農林省
水産講習所研究報告

第 9 巻

THE JOURNAL OF THE SHIMONOSEKI COLLEGE OF FISHERIES

Vol. 9.

農林省水産講習所
下関市吉見

Published by
the Shimonoseki College of Fisheries
Yoshimi, Shimonoseki City, Japan.
1960

農林省水産講習所研究報告

第 9 巻

総　目　次

第 1 号（昭和35年1月）

A Proposal Giving Some Significances upon Micro-distribution of Fishes for the Comparison of the Fishing Efficiencies of Serial Gears Variously Constructed. …… Hiroshi MAÉDA …… 1

特　殊　二　重　網 …… 渡　辺　　亨 …… 11

"イタニグサ" *Ahnfeltia plicata* より寒天の新製造法に関する研究—I
…… 小島良夫・福島保明・香野　実 …… 43

ウニ塩辛に関する研究—I
ウニ塩辛の貯蔵中における成分変化について
…… 畑　幸彦・河内正通 …… 53

油なめし法の検討——其の二 …… 松沢定五郎・上田　正 …… 65

牛乳カゼインのビンナガ鮪幽門垂プロテアーゼに依る分解生成物に就いて—I
該生成物の二十日ネズミに対する栄養試験
…… 藤井　実・小松次郎 …… 83

第 2 号（昭和35年2月）

A Tentative Analysis of the Distribution Pattern of Tuna Projected on the Long-line
…… Hiroshi MAÉDA …… 89

第 3 号（昭和35年3月）

鯨と採油量の一考察
1958～1959年の南氷洋における第2極洋丸船団の捕獲頭数と採油量について
…… 片岡昭吉 …… 309

"イタニグサ" *Ahnfeltia plicata* より寒天の新製造法に関する研究——II
心太の脱色及び脱水について …… 小島良夫・田川昭治・香野　実 …… 317

"イタニグサ" *Ahnfeltia plicata* より寒天の新製造法に関する研究——III
伊谷寒天製造の工業化について …… 小島良夫・田川昭治・香野　実 …… 323

海洋性硫酸塩還元細菌に対する食塩濃度の影響 …… 畑　幸彦 …… 329
海洋性硫酸塩還元細菌の無機塩要求について …… 畑　幸彦 …… 347
海洋性硫酸塩還元細菌におよぼす重金属塩類の影響 …… 畑　幸彦 …… 363
魚鱗箔採製に関する二, 三の実験
…… 上田　正・長　親志・村里隆司・松沢定五郎 …… 377
ウニの塩辛に関する研究――Ⅱ
ウニ塩辛の貯蔵中における成分変化におよぼす食塩およびアルコールの濃度の影響について
……河内正通・畑　幸彦…… 383

THE JOURNAL OF THE SHIMONOSEKI COLLEGE OF FISHERIES

Vol. 9. (1960)

CONTENTS

No. 1. (January, 1960)

A Proposal Giving Some Significances upon Micro-distribution of Fishes for the Comparison of the Fishing Efficiencies of Serial Gears Variously Constructed. ..... Hiroshi MAÉDA 1

Construction of the Special Double Nets. ..... Tōru WATANABE 11

Studies on the New Method of Preparation of Agar-agar from *Ahnfeltia plicata*—I ..... Yoshio KOJIMA, Yasuaki FUKUSIMA and Minoru KŌNO 43

Studies on "Uni-Shiokara" —I
Changes in Chemical Composition of "Uni-Shiokara" during the Storage ..... Yoshihiko HATA and Masayuki KŌCHI 53

Considerations on Oil Tanning ..... Jōgorō MATSUZAWA and Tadashi UEDA 65

Hydrolysis of Casein by Protease in Pyloric Appendage of Albacore *Thunnus alalunga*—I
Nutritive Effect of the Mixture of Fragments from Hydrolyzed Casein on the Growth of the Mice. ..... Minoru FUJII and Jirō KOMATSU 83

No. 2. (February, 1960)

A Tentative Analysis of the Distribution Pattern of Tuna Projected on the Long-line ..... Hiroshi MAÉDA 89

No. 3. (March, 1960)

Some Consideration on the Factors Affecting on the Antarctic Whale Oil Production in 1958~59 by the Kyokuyō-maru No. 2 ..... Akiyoshi KATAOKA 309

Studies on the New Method of Preparation of Agar-agar from *Ahnfeltia plicata*—II
On the Decolorization and Dehydration of Crude Ager Gel
..... Yoshio KOJIMA,
Shōji TAGAWA and Minoru KŌNO 317

Studies on the New Method of Preparation of Agar-agar from *Ahnfeltia plicata*—III
On the Industrialization for Manufacturing Itani Agar
.....Yoshio KOJIMA,
Shōji TAGAWA and Minoru KŌNO 323

Response of Marine Sulfate-Reducing Bacteria to the Salinity of Culture Medium
..... Yoshihiko HATA 329

Inorganic Nutrition of Marine Sulfate-Reducing Bacteria ..... Yoshihiko HATA 347

Influence of Heavy Metals upon the Growth and the Activity of Marine
Sulfate-Reducing Bacteria ..... Yoshihiko HATA 363

On Some Experiments for Preparing Pearl Essence
..... Tadashi UEDA, Chikashi OSA,
Takashi MURASATO and Jōgorō MATSUZAWA 377

Studies on "Uni-Shiokara" —II
Influences of Salt and Alcohol upon the Changes in Chemical Composition of
"Uni-Shiokara" during the Storage ..... Masayuki KŌCHI
and Yoshihiko HATA 383

A Proposal Giving Some Significances upon Micro-distribution of Fishes for the Comparison of the Fishing Efficiencies of Serial Gears Variously Constructed※

By

Hiroshi MAÉDA

Mesh size, colour or dye used, material and thickness of netting cord and many other elements of structure are thought to be important factors affecting fishing efficiency of gears. And considerably many and valuable reports were published in which the influences of these factors were studied technologically, field and laboratorial experimental ecologically or physiologically. But when we wish to, field experimentally, compare the fishing efficiencies of nets variously constructed with one another——especially when the length covered by each kind of net is not so long enough——, another factor, micro-distribution of fish individuals, becomes as much as or more influential and adequate attention should be paid to it.

And this report is written for the purpose of calling attention to its significance adopting the results of salmon drift-nets test operations which are thought to be one of the typical examples emphasizing this fact.

Before entering the subject, I must express my sincere thanks to Prof. Dr. D. MIYADI and Dr. T. TOKIOKA of the Kyoto University for their kind guidance and criticisms given on the present work. And I must also record here my hearty thanks to former Prof. M. TOYOTA of the Shimonoseki College of Fisheries and Mr. T. TAKAGI of the Nippon Suisan Co. Ltd. by whom I was so kindly given the records used in this study.

Data used in this study

Daily reports of salmon drift-nets test operations pursued during the period from April to August in 1955 by four research boats belonging to the Nippon Suisan Co. Ltd., Matsu-maru, Suzu-maru, Yoko-maru and Nikko-maru, were used in this study. These boats operated in the waters near the Aleutians (48°—52° N, 155°—180° E) cruising from east to west and catching five species of salmons (*Oncorhynchus nerka*,

※ Contribution from the Shimonoseki College of Fisheries, No. 287.
Received November 2, 1959.

O. keta, *O. gorbuscha*, *O. kisutch* and *O. tschawytscha*) using 250 sections of nets or a little less sections being constituted of following 18 kinds of nets of variable numbers of sections.

Net No.	material of cord	mesh size (sun=3.3 cm)	colour or dye used
1		4.3	Brown stained by Nichimō type
2		4.2	〃
3		〃	Brown stained by Nitto type
4	Ramie	〃	Deutrex*
5		〃	N. G.*
6		〃	Cutch fixed by $CuSO_4$
7		4.1	Brown stained by Nichimō type
8		4.4	Cutch colour
9		4.3	〃
10		4.2	〃
11		〃	Deep cutch colour
12		〃	Light blue
13	Amilan	〃	Blue
14	(Nylon)	4.1	Cutch colour
15		4.0	〃
16		3.9	〃
17		4.3 and 4.0 mixed	〃
18		4.2 and 4.0 mixed	〃

Note : * indicates the nets the details of staining of which are not clear.

And besides the section numbers of respective kinds of nets used in respective operations, catches by respective kinds of nets in a little more than a half number of operations are shown being partitioned into respective species, while in the rests, sums of catches of five species of salmons by respective kinds of nets and total catches of respective species by a row are described. And there is no record in which the frequency distribution of respectively occupied sections is described. Therefore, against

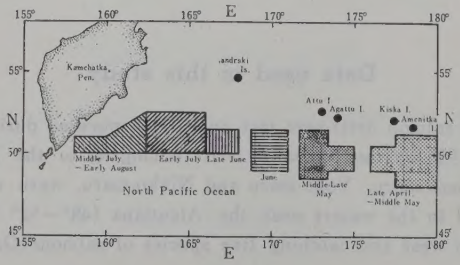


Fig. 1. Sketch chart of fishing ground, showing the migration of it due to passing of season.

the fact that it is more desirable to treat the data separating into each species, I can not help adopting the total catch (sums of catch of five species) for the purpose of increasing the number of operations avairable. And averages of them per section by respective kinds of nets in respective operations (this is hereafter called simply as catch rate) deviate from less than 1 individual to atmost 20 per section, mostly from 2 to 7.

Results

1. Preliminary consideration and transformation of catch rates

In order to compare the catch rates by various kinds of nets with one another, I must, at first, examine the frequency distribution of respectively occupied sections, then each variate should be transformed following the adequate method into the type of frequency distribution fit for observed ones, because the frequency distribution of such example of low catch rate as these is hardly expected to fit for the normal one. But in spite of this fact, I can not presume the actual frequency distribution from the original records. Accordingly, there are only two ways treating the original records ——either to use simply mathematical mean or to treat the data setting hypothetical distribution of which is as POISSON'S one which is only one theoretical distribution presumable from the original records. While, I reported that the frequency distribution of respectively occupied sections of salmon drift-net in the same waters near the end of the fishing season in 1952 follows THOMAS' or PÓLYA-EGGENBERGER'S distribution but to see roughly it is not so far from POISSON'S (MAÉDA, 1953 A). Therefore, I was obliged to treat the data setting as POISSON'S one. And in order to treat statistically POISSON'S or slightly contagious distribution, each variate should be transformed into square root value for the purpose of normalizing the distribution. Therefore, hypothetical frequency distribution of respectively occupied sections of each kind of net in each day by each boat setting to follow POISSON'S one is computed from the following formula: $N_x = Nm^x e^{-m}/x!$ ..... (1) (Here, N_x is number of sections expected to be occupied by x individuals when N sections of drift-nets are used. m is mathematical mean of catch per section). Then, average of transformed catch, x', is computed using the following formula:

$$x' = \frac{\sum_{x=0}^{xi} \sqrt{x} \cdot N \cdot m^x e^{-m}/x!}{N} = \sum_{x=0}^{xi} \sqrt{x}\, m^x e^{-m}/x! \quad \cdots\cdots (2)$$

Symbols are the same as in Formula (1). Practically, x is limited from 0 to the smallest x_i, where x_i is defined by $\sum_{x=0}^{x_i} m^x e^{-m}/x!$ which becomes as equal as or a little more than 0.99.

2. Variation of relative catch rates depending on difference of season and locality

It is easily assumable that, when density of individuals is high, catch rates of all

kinds of nets may increase while *vice versa*. Accordingly, when we wish to compare the efficiencies of nets with one another, it seems to be better to adopt the ratios of them, because this makes it possible to eliminate the deviation due to daily deviation of density of fishes. And for convenience's sake of comparison, the words "relative catch rate" is used hereafter representing the ratio of catch rate of a certain nets to

Table 1. Frequency distribution of section numbers of respective kinds of nets used by Matsu-maru in 85 operations.

Net No.	Section number						
	0	1—5	6—10	11—20	21—30	31—40	41<
1	4	20	61	0	0	0	0
2	2	1	1	28	11	9	33
3	49	6	30	0	0	0	0
4	15	70	0	0	0	0	0
7	34	20	31	0	0	0	0
8	2	0	3	3	77	0	0
9	4	1	80	0	0	0	0
10	6	78	1	0	0	0	0
11	9	76	0	0	0	0	0
12	5	80	0	0	0	0	0
13	7	78	0	0	0	0	0
14	25	0	60	0	0	0	0
15	39	0	46	0	0	0	0
16	54	0	31	0	0	0	0
17	73	0	12	0	0	0	0
18	0	0	0	1	0	3	81

Note : Frequencies of net Nos. 5 and 6 are omitted because of less frequencies used.

that of net No. 2 (Ramie, 4.2 sun mesh and brown stained by Nichimo type) for net Nos. 1～7 or net No. 18 (Amilan, 4.2 and 4.0 sun mesh mixed and cutch colour) for net Nos. 8～18 because the number of sections of these kinds of nets used in each operation is the largest of all consequently the deviation of catch rate due to accidental error is expected to be the smallest.

Before entering the principal subjects, whether or not the relative catch rates vary depending on the difference of season and localities should be examined because fishing season of off shore salmon drift-net fishery is rather long and fishing ground of it covers considerably wide area consequently it is highly probable that efficiency of even the same kind of net may not be the same throughout the fishing season and all over the fishing ground but may change depending on growth and changes of physiological (during the season, gonads are matured) or oceanographical conditions. But practically, fishing ground was limited in the range from 48° to 52° N and moved from east to west covering from 155° to 180° E, from the beginning to the end of fishing season. Accordingly, the difference of latitude is able to be negligible and

the differences of longitude and season are unable to treat separately. Thus, these factors are representable simply by the difference of longitude. So, the relation between longitude and relative catch rates is examined. And several examples of the results are illustrated in Figs. 2(1)—(3), which tell us that the relative catch

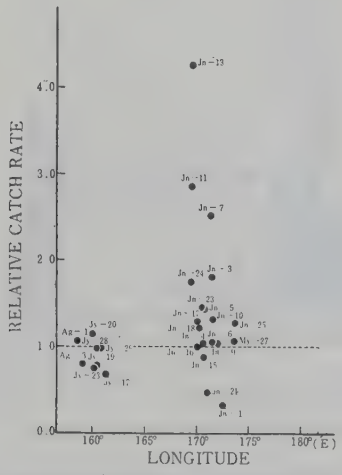


Fig. 2(1). Longitude—relative catch rate relation graph.
(Amilan, 4.2 sun mesh, deep cutch colour: By Suzu-maru).
Abbreviations
Ap : April My : May Jn : June Jy : July
Number illustrated in figure indicates the date of operation.

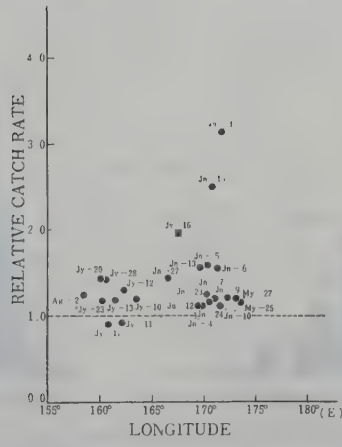


Fig. 2(2). Longitude—Relative catch rate relation graph.
(Amilan, 4.2 sun mesh, blue: By Nikko-maru).

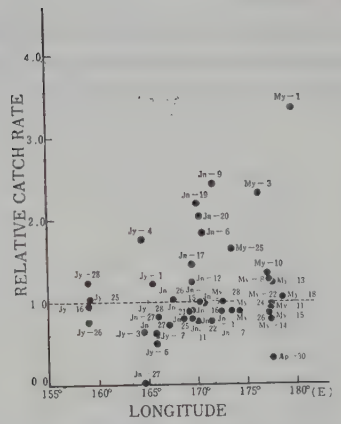


Fig. 2(3). Longitude—Relative catch rate relation graph.
(Amilan, 4.2 sun mesh, light blue: By Matsu-maru).

rates do not vary depending on longitude, while some relations between deviation of them and longitude are alluded which will be discussed in "consideration".

3. Comparison of fishing efficiencies of nets constructed variously

(Consideration upon the frequency distribution of relative catch rates).

It is deducible from the facts mentioned in the preceding paragraph that there is

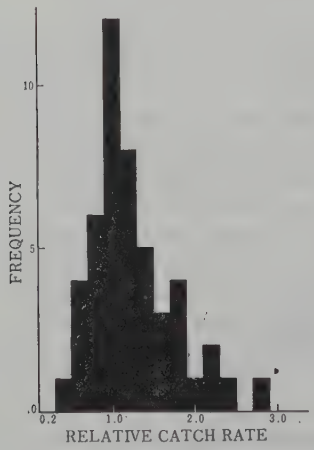


Fig. 3 (1). Frequency distribution of relative catch rate.
(Ramie, 4.3 sun mesh, Nichimo-zome: By Matsu-maru).

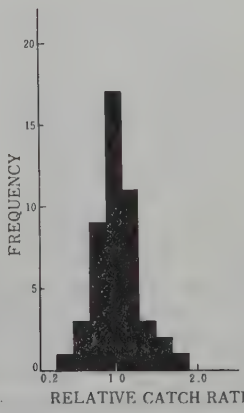


Fig. 3 (2). Frequency distribution of relative catch rate.
(Amilan, 4.3 sun mesh, cutch colour : By Matsu-maru).

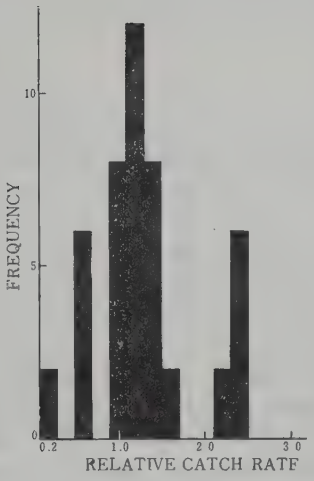


Fig. 3 (3). Frequency distribution of relative catch rate.
(Amilan, 4.2 sun mesh, cutch colour: By Nikko-maru).

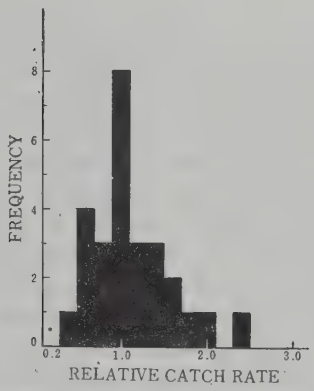


Fig. 3 (4). Frequency distribution of relative catch rate.
(Amilan, 4.2 sun mesh, blue: By Suzu-maru).

no need to treat the data stratifying into several longitude groups. So, frequency distributions of relative catch rates regardless of longitude are examined and several examples of the results are shown in Figs. 3 (1)—(4), which tell us that most of modes are observable at 1 or thereabout and that, considering together with less frequencies, it seems to be difficult giving any significance upon the difference of frequencies between lower and higher than 1. Accordingly, I cannot help considering, so far as the present study has concerned, no significant difference of catch rates can be admitted to be caused by such small differences of mesh size and colour as used in these operations.

Consideration

As mentioned in the last section of the 2nd paragraph in the results, we will find easily from Figs. 2(1)—(3) that the station showing large deviation of relative catch rates from 1 towards larger or towards smaller is frequently observable in the waters east parts of the fishing ground, while this deviation becomes smaller and smaller in company with the migration of stations towards west and relative catch rates are apparently converged into 1 —— although the convergence of relative catch rate is represented here as if simply due to the migration of fishing station, difference of operation date may also contribute as significantly as difference of locality. And, in any case, adequate attentions should be paid to this apparent convergence. Figure 4 represents an example of the relation between catch rate and longitude. And this

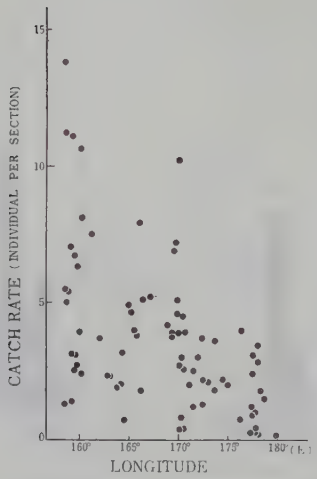


Fig. 4. An example of catch rate—longitude relation graph.
(Net No. 2, by Matsu-maru)

figure suggests that, as commonly recognized, the catch rate in the beginning of fishing season is low but increases with passing the season. Accordingly, it is probable that when catch rate is low, the relative catch rate may be heavily suffered from the influence of accidental error and fluctuate severely, while when catch rate is high, accidental error becomes less influential and relative catch rate may fluctuate not so severely. And when the size of sample is the larger, the larger deviation of relative catch rate is observable. Of course, these facts may more or less contribute to cause the apparent convergence. While this figure also suggests that even the daily catch rates in the water near the west limit fluctuate severely, against the fact that those in the waters near the east end seem to fluctuate not so severely. Accordingly, deducing from the apparent convergence of relative catch rates and fluctuation of daily catch rates, it may be one of the ways of thinking to regard that, in the waters near the east limit, not so much individuals are aggregated showing strong dishomogeneity observable within a row, while with approach to the west limit, dishomogeneity observable within a row becomes weaker and weaker but that between days,——consequently this may well be thought that between rows——, is still as influential as or becomes a little more influential than in the waters near the east limit. Therefore it is probable that the length of each kind of net used in the water near the west limit may be adequate being able to obtain accurate relative catch rates because if longer some influences of distribution of large scale may be introduced while if shorter scarcity of total catch by each kind of net or short length is afraid to introduce the influence of accidental error. But the length of each kind of net is not suitable in the waters near the east limit —— perhaps too short to get accurate catch rate

overcoming the dishomogeneity of distribution of fish individuals within the waters covered by a row, although the length itself is rather invariable.

Conclusion

Summarizing the facts mentioned in the chapters of results and consideration, I wish to conclude as follows: These test operations were planned for the purpose of finding out the difference among the fishing efficiencies of nets variously constructed, but no clear conclusion fit for this purpose can be obtained because length covered by each kind of net is not long enough comparing with the scale of micro-distribution of fish individuals, especially in the east waters, and this makes unable to obtain the accurate and less deviating catch rate. And if we wish to obtain accurate conclusion fit for the purpose I propose to pursue far well designed test operations of far large scale in such fishing ground as the waters near the west limit where individuals are expected to be distributed densely and rather uniformly within the waters covered by a row——decreasing kinds of nets used (consequently length of each kind of net is elongated for the purpose of overcoming the dishomogeneity of distribution of individuals within short range), using many boats (because large deviation of catch rate or relative catch rate is expected, statistical size of samples should be far increased, against the fact that fishing season, especially suitable season for the test operation, is limited and it is unable to increase the number of operations capable to be pursued by each boat), and moreover recording the frequency distribution of respectively occupied sections by respective species although it may have much obstacles to make this plan into practice due to technological conditions, limitation of commercial system *etc.*

Summary

1. This report is written for the purpose of calling attention to the significance of micro-distribution of fish individuals for comparison of fishing efficiencies of serial gears variously constructed with one another.
2. As typical examples, daily reports of salmon drift-net test operations pursued by 4 research boats of the Nippon Suisan Co. Ltd. in the waters near the Aleutians during the fishing season in 1955 are adopted.
3. It is one of the foci of this report that, first, hypothetical frequency distribution of respectively occupied sections assuming as POISSON'S one is estimated, next, each variate is transformed into square root value and then averages of transformed values are used in the consideration, because the frequency distribution in such examples of low catch rate as these is hardly expected to be normal and no frequency distribution except POISSON'S is presumable from the original records moreover POISSON'S is expected to be not so far from the actually observed one.
4. The relation between longitude and relative catch rate (average of transformed catch rates of respective nets divided by that of Net No. 2 or No. 18) is examined

for the purpose of finding out whether or not relative catch rates vary depending on difference of season or locality of fishing stations. And several examples showing this relation are represented in Figs. 2(1)—(3). While no clear relation, excepting that between longitude and deviation of relative catch rate, is observable.

5. Examining the frequency distribution of relative catch rates regardless of season and locality [Figs. 3(1)—(4)], we can not find out any significant difference among fishing efficiencies caused by such small differences of mesh size and colour as adopted in these test operations.
6. Relative catch rates in the east parts seem to deviate largely but they are converged into a certain value with approach of fishing station to the west limit. While even the daily catch rate in the waters near the east limit seems to fluctuate severely.
7. The above-mentioned facts are thought to be due to the fact that length covered by each kind of nets used in each operation is too short, consequently, it is highly expected that relative catch rate is strongly affected by the micro-distribution of fish individuals.
8. Deducing from the apparent convergence of relative catch rates and the fluctuation of daily catch rate, it may be one of the ways of thinking to consider that, in the waters near the east limit, not so much individuals are aggregated showing strong dishomogeneity observable within a row, while with approach to the west limit, dishomogeneity observable within a row becomes weaker and weaker but that between days, which may well be thought to be that between rows, is still as influential as or become a little more influential than in the waters near the east limit.
9. If we wish to obtain the adequate conclusion for the aim of this test operation, I recommend to pursue the test operations in the waters near the west limit decreasing kinds of nets used while using many boats, and moreover, frequency distribution of respectively occupied sections by respective species should be recorded.

References

MAÉDA, H., 1953 a. *Bull. Jap. Soc. Sci. Fish.*, **19** (4), 305—318.
MAÉDA, H., 1953 b. *Records Oceanogr. Work Jap. N.S.*, **1** (2), 86—93.
TAGUCHI, K., 1959. *Bull. Jap. Soc. Sci. Fish.*, **25** (5), 335—341.

特殊二重網※

渡辺　享

Construction of the Special Double Nets※

By

Tōru WATANABE

The present report is concerned with the constructions of the special double nets* and study of their effort on more getting a good catch than that by single nets without loss of fishing efficiency. Viewed in this light, the constructions were estimated by the proportion like that fish is caught in both main and outer meshes simultaniously with laying over the meshes of each nets. At field survey, each compornent was regulated by testing the structure of the nets, then almost elements necessary for the planning were determined. In July 1957, pink salmon were caught more 25 per cent in quantities by this nets of the pelagic drifter off the coast of Kushiro, Hokkaido, Japan, than those by the single ones. Actually, fishing on board carried on smoothly without loss of efficiency.

From the results obtained by the present investigations the coefficients necessary to design the nets were also determined.

緒　言

1956年の北洋鮭鱒漁業出漁に関する日ソ漁業協定はかなりきびしい制約を受け，この制限条件中鮭鱒流網使用反数の問題は我々水産関係者の苦悩を深刻化したと見受けられた。即ちこれは鮭鱒独航船個々の操業能率を根底から崩壊せしめる条件であるからである。この制限が実施される以前の北緯48°—10′以北の独航船の一日当り使用反数は約450反であったものが，1959年度の操業実態は東経170°—25′以東は流網投網距離15km，水産庁標準換算使用反数一日当り330反，この以西は投網距離12km，標準反数264反に制限を受けた。従って高度操業能率を持っておった従前に比較し，前者は約26.7 %，後者は約41.3 %の操短を余儀なくされ，漁獲能率を著しく低減せしめられる実情となった。

これらの操業実態を時間的に集約して見るに，

使用反数450反の場合

※ 水産講習所研究業績　第288号，　1959年11月2日受理
Contribution from the Shimonoseki College of Fisheries, No. 288.
Received November 20, 1959.

* Application for the patent is pending.

Table 1. Each operating time of salmon drifter occupied in 450 boxes.

Operating time	Time of one round operation	Speed of layout & hauling	Summary
Time of layout	2 h—00 m	187.5 m/min.	Layout speed is about 5～6 miles per hour.
Drifting time	6 h—00 m		
Hauling time	8 h—00 m～10 h—00 m	46.9 m/min.～37.5 m/min.	Hauling speed is about 1.2～1.5 mile per hour.
Time of going & returning to mother ship, etc.	6 h—00 m～4 h—00 m		
Total	24 h—00 m		

これが操短されて約270反，即ち40 %使用反数を減じた場合

Table 2. On presumable each operating time of salmon drifter occupied in 270 boxes.

Operating time	Time of one round operation	Speed of layout & hauling	Note
Time of layout	1 h—12 m	187.5 m/min.	Same speed when the boat operate on 450 boxes.
Drifting time	6 h—00 m		
Hauling time	4 h—48 m～6 h—00 m	46.9 m/min.～37.5 m/min.	do above.
Time of going & returning to mother ship, etc.	12 h—00 m～10 h—48 m		
Total	24 h—00 m		

上記の如く使用反数450反と270反の場合を比較すると，母船往復その他時間6時間—00分～4時間—00分に対し12時間—00分～10時間—48分となり，この時間は漁獲能率を増進せしめる立場から見ればできるだけ低減せしめる必要があるから，使用反数270反の場合，操業一日当りの時間的余裕は6時間—00分～6時間—48分あるはずになる。使用反数450反の場合網流し時間6時間—00分は操業能率を高める方法として多少検討の余地があるものと想像されるが，この問題は別途に考究するとして，当面この余裕時間約6時間 -00分を直接漁獲尾数増進に結びつけるように操業の実態改善に徹することが必要である。

これは漁業の国際性によって生じる国家相互間の漁業協定は相互の信頼のもとに厳守する必要があり，これに対処する方策は極めて科学的に合理性をもった経営管理を樹立することを要求されると思われるからである。

この余裕を生ずると推定される稼動時間は母船1隻に附属する独航船約30隻を有する母船式鮭鱒漁業において附属独航船の合理的な配船と漁獲物受渡し関係に要する時間その他母船と附属独航船間の総合能率を増進するために利用することが充分考えられ，対処さるべきであるが，茲においては流網一反当りの羅網増進

改善対策に問題を絞り考究の重点を置くことにした。即ちこの改善が実現された場合これによって派生すると推定される操業状態から見て留意すべき要点を検討すれば，大体次のようなものである。

（1）投，揚網時の能率低下

即ち投網時特殊流網の纏絡増加によるもの，主として揚網時の魚体その他纏絡物の取外しと特殊流網構成の複雑性による網捌きによって生ずる作業能率の低下によるものである。

（2）特殊流網構成の複雑性による荒天中の主として網捌きによる能率低下。

（3）特殊流網による荒天中の棒網増加傾向を生ずると思われることによる能率低下。

（4）特殊漁網積込による重量増加による荒天中の漁船の耐航性と安定性からくる能率低下。

以上の各点に対し，主として検討を行うべきである。

而して，(4)は流網使用反数の減少によって大体問題はないと思われ，(3)は別途に漁網緩衝装置によって対策を研究することとし，(1)(2)による作業能率低下，即ち一反当りの作業時間の増加は乗組員を増加することなく操業一日当り余裕時間6時間-00分を(1)(2)の項に充当するとして操業中の時間的配分について一応次の如く推定した。

（イ）特殊二重流網を使用した場合は添網を魚群游泳方向に常に相対するよう投網する必要がある。投網距離約12kmとすれば，これに要する航走時間約1時間--00分，各独航船に過重される平均航走時間約30分

註・特殊二重流網の添網側を交互になるように連結すればこの過重される航走時間は無視してよい。

（ロ）この網の投網に要する時間の増加は殆んど見なくてよいと思われるが，約10 %作業能率低下を見込めば約7分。

（ハ）この網の構成上の複雑性による荒天中の主として網捌きの能率低下を約15 %とすれば約45分。

（ニ）荒天中この網の棒網増加による能率低下約10 %を見込めば 約30分(イ)(ロ)(ハ)(ニ)各項の能率低下所要時間合計約1時間52分になるとすれば

（ホ）揚網時の魚体取外し，その他の纏絡物取外し，特殊二重網構成上の複雑性による網捌きの能率低下などに充当し得る時間は約4時間08分になる。即ち揚網時間は5時間00分＋4時間08分＝9時間08分，揚網速度 24.6 m/sec. で計算上約40 %揚網速度の低下を許容し得ることになるが，実用的には約30 %揚網速度の低下を差支えない限度として漁網構成上の複雑性による必然的の能率低下を容認し得る数値と判断して1956年より鮭鱒流網改良の考察と研究を始めた。

I　特殊二重網の予備的考察

鮭鱒流網の如き一枚網の浮き流網に魚体が羅網する状態を考察するに，魚体は或る游泳速度で網地に近づき主として視覚と或は漁網の発する水中音を感覚してこれを避けんとすると思われる。然し現在の漁法上から見た一般的通念は，斯かる漁網に対しては主に視覚により漁網を認め逃避するとしている。従って魚体は網地を認め，これを避けんとして左右，上下，或は後方の各方向に転向せんとする。底魚の胸鰭等の大きいものは網地に吻端附近を触れ，その後或る程度後退逃避することもできるものもあるが，一般の上層魚，例えば鮭鱒類の如く魚体肥満度小さいものはかなりの游泳速度をもち，また胸鰭等比較的に小さいものは網地に直面して直ちに後退できず，かなり大きい游泳回転圏をもって反転すると思われる。かかる魚体運動に対して浮き流網網地の羅網性能は，(1) 主として魚体を網目に刺さして捕る。(2) 一度網地に触れ又は触れんとして反転せんとした魚体・鰭等に網糸が纏絡して捕られる。この2方法のうち何れかに重点をおいて網目型の変型程度を決定し，即ち縦横各々の縮結程度を定め，一般的には横の縮結の程度によって解決せんとしておる。鮭鱒流網においては以上の点を考慮し，実績に徴し縮結 40～45 %程度に決定されている。この縮結程度は一枚網鮭鱒流網においては大体変更しがたいものと見てさしつかえない。

従って従来から鮭鱒流網の縮結その他の設計は大同小異であったが，羅網率はかなり上昇が見られた。こ

れは主として使用網地撚糸の性能の差異によって生じたものであると一般的に認められている。即ち綿糸，ラミー，ナイロン各撚糸の順に変遷した。ここに各種撚糸の性能の概要を対比すれば第三表の通りである。

Table 3. On physical tests of sort of threads applied salmon drift nets on the North Pacific Ocean.

Thread		Breaking stress kg		Breaking stress of loop kg		Diameter mm		Flexibility by Kanti lever method mm	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Cotton #20	3 strands /15 yarns	7.9	9.0	5.4	6.1	1.12	1.27	48	95
Ramie	#17 /5 strands	18.0	28.3	9.0	12.3	1.00	1.20	6.5～7.3	6.0～6.5
	#8 /2 strands	13.7	22.0	6.5	9.0	0.92	1.12	—	—
	#6 /2 strands	17.5	27.0	8.6	12.0	1.05	1.23	—	—
Amilan 210 D. 300 type	3 strands /15 yarns	19.9	16.7	11.7	10.2	0.860	0.95	6.0～6.5	5.3～6.0
	4 strands /16 yarns	21.0	17.8	12.2	10.8	0.900	0.995	—	—
	3 strands /18 yarns	23.2	20.0	13.8	12.2	0.925	1.022	—	—

綿糸撚糸からラミー撚糸に代った主な性能上の差異は撚糸の柔軟性，即ちカンチレバー法によれば湿潤時綿糸95に対しラミー6.0で6.3 %に当り格段の差異が認められ，これによって反当り鮭鱒羅網率は決定的に優劣を生じたといえる。次にラミー撚糸がナイロン撚糸に大々的に代ったのは1952年頃からで，日本水産1954年度母船式鮭鱒漁業附属独航船調査報告によれば，ラミー撚糸に較べナイロン撚糸は約20 %の羅網増加が確実に認められ，また1953年日本漁網の独航船からの聴取によれば，ラミー撚糸に比べナイロン撚糸は羅網率

Table 4. Comparative table on physical tests of Ramie & Amilan threads of salmon drift nets.

Items \ Threads		Ramie 7#/5 strands in percent	Amilan 210 D. 300 type 3 strands/15 yarns in percent
Breaking stress	Dry	100	110
	Wet	100	59
Breaking stress of loop	Dry	100	130
	Wet	100	83
Diameter	Dry	100	86
	Wet	100	79
Flexibility by Kanti lever method	Dry	100	92—89
	Wet	100	88—92

1.25～1.30で，これが回答中の百分率は38.5 %であり，1.30～1.45のものは23.0 %，1.70～2.00のものは15.5 %，2.00以上のものは23.0 %であり，大体ナイロン撚糸はラミー撚糸に比べ約20～30 %の羅網増加が認められるとして大過ない数値であることがわかる。これが原因とされる撚糸性能上の差異を鮭鱒流網用の代表的規格品により第4表に示す。

アミラン撚糸はラミー撚糸に比べ抗張力は湿潤時59 %で劣り，ループ結節強力は湿潤時漸く83 %でラミー撚糸が操業中主として腐敗によって強力減退するから結局あまり優劣なしとみなされ，カンチレバー法による柔軟性においてもアミラン撚糸が少し劣る数値で大体同じと見てよい。しかし撚糸の太さにおいて特に湿潤時アミラン撚糸はラミー撚糸に比べ79 %であり，実際操業中はラミー撚糸は遙かにけばだち，見かけ上の太さをより大きくするから，この差異を一層大きくする。撚糸性能上から見た羅網率の差異はアミラン，ラミー各撚糸の対比に関する限り水中における撚糸直径の差異即ち魚体に可視され難い細い撚糸であることが重要素であると判定してよい。従って鮭鱒流網は可視され難い流網に構成し設計することが重要な条件であると思われる。

鮭鱒流網網目は前述の如き游泳運動をする魚体を羅網せしむるためには，先ず第一条件として網目が常に魚体を刺しやすい形状になっていることが必要である。浮き流網は静水中では一枚の屏風のように垂直平面が帯状に展開しているが，波浪中の網目は波浪の山と谷が反覆する毎に水面上の浮子は上下運動をせしめられ波浪の山が過ぎる瞬間に浮子方の浮力が網目両脚を片目増しに衝撃的に伝播され，次にその直下の沈子方が衝撃的に引上げられ，波浪の山が過ぎ去れば，網地・沈子方の沈降力で徐々沈下する状態を繰返す。従って網目は波浪の山が来る度に縦方向に引き伸ばされ，次の瞬間に沈子方と網地が引上げられ，そこで網目は横の方向に拡がらんとし，波浪の谷が来れば浮子方が沈下し，沈子方は上昇しているから，網地がたるむ傾向を生じ，網目は横方向に開く。次に網地・沈降方の沈子力が作用して沈子方・網地が沈下して落着き，網目型が正常に復元することになるが，波浪の高さと周期に対する流網浮力と沈降力と沈降速度の関係から網目型は正常型になりがたく，概して網目変形度合は沈子方網目・中間・浮子方に近い網目の順に大きい。従って縮結によって生じた網目型に近い状態に保たれている程度は浮子方に近い網目・中間・沈子方に近い網目の順になっていることが多い。

魚体は，かかる網目の変形と網地全体の動揺を繰返している網目に進行して来るから浮子方に近い網目は刺し易く，中間・沈子方の網目の順に縺絡の程度を増加し網目に刺さらんとしても，網目が常に開いている部分が狭く，網地自体の動揺も大きいから魚体の鼻先に網目脚が触れる率が多く，また網地の動揺を視覚する場合網地を幕に感ずる率が多くなり，魚には可視されやすい網地として感覚されるから羅網率は低下し，また網目に確実に刺さる率が低いから，一度羅網せんとした魚体も外れる率が多いと思われる。この外れた魚体，即ち目掛り魚は遡河時かなりの魚体数が認められている。当業者間においては一般に羅網尾数の約50 %の目掛魚があると推定している。

これが計算の基礎は明らかでないが，現場当業者のこの種の推定はかなりの妥当性がある数値であると思われる。我々が現場において確実に見ることができる目掛魚は揚網中の離脱尾数で，水産講習所高瀬は1959年母船式鮭鱒漁場において平穏な海面時は5反に1尾，Slight sea 程度の海面では2反に1尾位の離脱尾数が認められたという。これらは羅網平均尾数反当り5尾とすれば，前者は4 %，後者は10 %の離脱尾数を認められる程度で，全目掛魚に対して我々が現場で確認する尾数はあまりに少ない。即ち，目掛り魚の大部分は現在一般に使用されている一枚鮭鱒流網の羅網性能にかなりの欠陥があることを認めざるを得ない。

即ち，目掛り魚の大部分は，流網に一度かかった後離脱するものであり，離脱の主要原因の一つは波浪中の網目が一定水位に一定網目型に開いていないことによると思われる。これが対策としては波浪により鮭鱒流網に作用する衝撃的上下動揺が主体をなすから，これを緩衝する装置により或る程度防止して，目掛り魚を減少することがかなりできると思われる。

この方法として

（1）実用新案第497532号　流網
（2）特願昭32—19970号　沈子方に緩衝装置をつけた流網
（3）実願昭33—42969号　流網
（4）特願昭34—13403号　漁網
（5）特願昭34—16684号　網地に緩衝浮力体を有する漁網
以上を一応の研究の対照としている。

前述は専ら一重網の魚体羅網時の動態考察を主として述べたが，かような一枚刺網類に対し二枚・三枚網がある。

この三枚網の起源は Elizabeth 一世時代，即ち16世紀フランス人によって英国に Trammel Net(Three Nets) として初めて紹介された。これは英国において主に河川に遡河せんとする鮭鱒類を沿岸近くで獲り，又底刺網として鰈類もとった。

Trammel Net は身網の両側に網目の大きい添網をとりつけ，身網網丈は添網網丈の二倍位になっている。この構成は終戦後我が国沿岸各地でかなり使用されている三重底刺網と同じものであり，これが改良された安部一の特許昭和30年第1326号漁網はこの三重網網丈中間において，身網と添網を数段に亘り直接縫合し添網網丈に対し身網網丈は Trammel Net と同じく大体二倍位にたるませるを標準としている。これら三重網は大体沿岸の底刺網用に小規模に用いる操業実態に適合するように考案されているものとみなされる。

即ち，魚体の羅網状態は大きい網目の添網を潜り，身網網目にあたり，魚体は一般に後退しがたいから，魚体運動により前進し，身網網地を押して他側の添網網目をくぐり身網は充分たるんで余裕をもっておるから他側添網網目と身網によって袋状を形成し，この中に魚体がとじこめられる羅網状態になる。

従って添網網目形は常に魚体がくぐりやすい状態に構成され，魚体は上述の如く他側の添網網目と身網によって袋状の中にとじこめられるから，身網網目に刺さると共に魚体鰭各部に身網・添網各網目脚が纏絡する。また浮遊物もかかりやすいが，取外し難い状態に纏絡する。

かかる羅網状態であるから操業状態は揚網中魚体その他纏絡物の取外しに最も多くの労力と作業時間を要し，次に漁網補修・網捌き・整頓・投網準備に多くの時間を要す。

この点沿岸漁業は漁場・漁船の制約上投網反数を可及的に多量用い操業能率化をはかるように編成しがたいから，前述漁網操作上生ずる悪条件は大して問題にならない。

而して母船式鮭鱒流網においては緒言中に概説した如く実質的に使用反数制限を受けている今日の操業実態から，実用的には約30 % 揚網速度を低下し得る程度と思われるから，漁況の如何によっては揚網時間の占める程度が過重となって操業中の各作業時間が平衡を失し総合的に見た操業能率を低下せしめる懸念がある。

これに対し1959年出漁母船附属独航船の一部に対し添網網丈に対し，身網網丈を40～50 % のたるみの各種二重・三重網・すじ網の試験操業が実施され，これ等は在来の三重網の約100 % のたるみに比べよほど少なく調整され，羅網魚体の取外しと網捌きはかなり良くなっていると想像され，大洋漁業富永は当初は独航船乗組員が網捌きに難渋するとの報告があったが，その後取扱いに慣れ，この点或る程度緩和されたという。

前述の如き浮き流網用三重網の波浪中における漁網運動状態を想定するに，例えば波浪の山が来れば浮子方が持ち上げられるから，身網・添網共に引き上げられる。しかし身網網丈は添網網丈よりかなり大きくたるんでいるから添網の方は前述一枚流網と同じく衝撃的に引き上げられ，添網網目は縦方向に変形する。身網と添網の結着部もほぼ同じく衝撃的に引き上げられるが，身網網丈のたるみは添網網丈間に水流にふかれてふくらんでいるから，この部分の身網は添網と同調して上方向に引き上がらない。波浪の谷が来れば添網浮子方が下方向に動き，添網は網地自体と沈子方の沈降力は浮子方の下方向運動を添網網地に直ちに吸収しきれず，添網網目は横方向に変形してたるみ気味になる。

身網は網地のみの沈降力のみで小さいから，添網網地の下方向の動きに同調しない。身網網裾は添網とともに吊糸で沈子綱に連結しているから波浪による網地の上下運動は身網のたるみがあるので，身網は添網に

同調せず一枚網に比べ，この不同調が甚しく，また複雑な力作用をすることになるから網裾の網成りを一層悪化させる。

海面静穏なとき浮き流網の二重網・三重網は水流によって添網網丈間にたるんでいる。身網はある時はふかれて添網の一方にふき出て襞を生じ，又ある時は両側添網がほぼ接し，その間に身網のたるみによって襞を生じ，また添網と身網との結着部に身網のたるみが沈降して襞を生ずる。

在来の一枚網の鮭鱒流網において，ラミー撚糸からナイロン撚糸に代った主な性能上の差異は前述の如く撚糸直径の大きさが羅網率に最も影響されたと見る実績があるから，魚体に可視されやすい網地であることは極めて注意すべき問題であり，また，三重網等身網がたるみ，襞を生ずる流網は透明度高き漁場においてはかなりの影響があると思われる。

即ち視覚は映像を瞬時残存する性質があるから身網と添網の動揺の不同調と身網のたるみによって生ずる襞の動きは，一種の動く幕の如く視覚されて強く網地を魚に感知させやすく，更に駆逐作用さえ生ぜしめることもあると思われる。

以上の如く推考される悪影響は，1959年鮭鱒母船附属独航船により試漁された身網のたるんだこの種二重網・三重網・すじ網が透明度良き海況において羅網率はあまり良好でなかったと母船各社幹部から説明を受けたことから，この予備的考察を一応妥当ならしめていると思う。

Ⅱ　特殊二重網の構造

特殊二重網の構造を決定するに当って，鮭鱒流網の作業能率を低下することなしに羅網性能を向上せしめることを目的として考究するには次の如き条件が必要であると思われる。

（1）母船附属鮭鱒独航船の操業実態から揚網速度を在来の一枚網流網に比べ30％以上の低下は如何なる操業状態においても許容すべきでない。従って，三重網にするより二重網の改善を主眼として網捌きの場合可及的簡略であるような構成にする必要がある。

（2）二重網とした場合添網方向から水流があたれば，身網・添網の水流による抵抗差によって両網が開く。この場合添網側方向から魚体が羅網するのみでなく，身網側からも游泳があるから，その時の羅網性能を一枚網の羅網性能以下に落したくない。従って（1）の条件を勘案して在来の一枚網の網成りと編結は変更すべきでない。

（3）二重網の構造は出来る限り海中で認めがたい構成にする。これは本漁網考案には特に留意し，構成と設計の検討をした。従って，身網・添網共に垂直平面状になるように構成するがよい。また波浪中，身網・添網が大体同調して動揺することが望ましいから，このためには両網網丈はほぼ同長であることがよい。

（4）羅網率は一枚流網による目外れ魚を少なくすることで，かなりの増率が見込まれるはずであるから，羅網を確実にすることを第一目的として添網を取り付ける。第二の目的としては，魚体取外しを比較的に容易な羅網状態にすることを重視した。

鮭鱒の游泳状態は魚体型から推定し，また胸鰭は比較的に小さいから可成りの游泳速度をもっている。即ち1957年目合は標識放流によるものから推定し，一日当り移動速度12.3浬或は14.3浬といい，沖合において船側を平静に游泳するものから判定して約3浬/時前後であり，流網にあたってから恐怖状態で游泳したと推定されたものは約3倍の速度であった。従って，網地を発見して反転する前には游泳速度の関係からかなり大きい旋回圏をもち，また網地を認めてから胸鰭が小さいから游泳速度を低下することができ難く，そのまま網目に頭部を突込む傾向が強いと推定される。即ち，三重底建網で底魚各種，上層魚各種の羅網状態を見るに，各魚体，種別に著しい差異を認めるが，游泳状態，魚体型の似たものは，かなり類似の羅網状態を示す。

従って，鮭鱒魚体は添網を比較的に潜りやすく，魚体は身網にあたれば，身網・添網の間隔を魚体長に比

例して或る程度に定めれば魚体は両網地にまたがった状態に調整できるから，両網地の羅網作用が同時に作用して確実に捕えられる。

従って身網が袋状になるよう添網網丈に対して充分たるます必要はないと想定した。

（5）魚体に身網・添網が同時に作用して羅網するように構成するが，羅網状態は添網を潜った魚体が身網にあたらんとして反転せんとするが遊泳速度の関係から身網にあたり魚体をねじって逃れんとすれば，例えば身網・添網間隔を魚体吻端から胸鰭又は背鰭位に調節して居れば少くとも魚体後部は潜りやすい大きい添網網目であっても添網網目脚に触れることが大きいから魚体の平衡を失って魚体頭部は身網網目に刺さり，少くとも魚体中央から後部は添網網目糸に纏絡する。

両網間隔を適当に定め，主として添網の縮結を適当に調節すれば，添網纏絡の程度を適度に調整することができ，魚体取外しは一枚流網と殆んど変らない程度，即ち，魚体を引っぱれば網地から取外すことができるようになしうる。

以上の条件に適合する二重網の構成は両網地がほぼ同一間隔を保つような網成りその他を構成するが良い。

なお安部一の特許漁網である二重網は添網網丈間を数段に亘り直接縫合しているから，この部分は少くとも身網と結着部の関係から添網を潜り得る網目をかなりの範囲にわたり，つぶしている。これらの漁網は魚体が先ず添網を潜りやすいことが第一義と考えらるべきであるから，この点からも羅網率を低下する傾向が大きい。

（6）添網網目の大きさと網目型は魚体が潜りやすい状態であり，羅網時魚体反転運動するときは必ず添網が魚体に触れるような状態にすべきであり，なお魚体が添網に纏絡し網成りをこわす範囲を可及的に小範囲に止めるように網成りを調整する。

即ち，この必要は魚体が羅網時両網地の網目の変形を極力小範囲に止め，後から羅網してくる他魚体の羅網に極力支障を生ぜしめないようにするためである。二重・三重網は魚体の羅網により広い範囲に亘り網地に皺を生じやすく，これによって網目型を変形し，この影響を受けたかなりの範囲には他魚体は羅網しがたくなると想定されるからである。

大体上述の各点を考慮して，1956年二重流網構成の研究にとりかかり，同年特許出願し，1957年これが不備のため流網として再出願し，同年夏期釧路根拠鮭鱒流網漁船によって小規模な操業試験を行い，1959年3月19日特許出願流網が公告に決定している。

1　第一回試作の特殊二重網

1956年7月試作の特殊二重網仕様書の概要は下記の如きものであった。

この試作網は主として水流によって身網・添網の水中抵抗差によって両網の展開状態と，両網連結用の吊糸の長さと位置によって身網のふくらみの形状と程度，両網地各々の網目の開き工合と，波浪中の浮き流網としての網成りの検討を主目的とした。

仕様書明細概要

○身　網

アミラン210D×15本×121 mm目×62掛×15 m，6反

縁　編　アミラン 同上×18本×121 mm目×0.5掛

アミラン 同上×24本×121 mm目×0.5掛

アミラン 同上×36本× 85 mm目×0.5掛

口　編　アミラン 同上×27本×0.5掛

アミラン 同上×36本×0.5掛

○添　網

(イ)　アミラン210D×15本×224 mm目×32掛×70目，3反

(ロ)　アミラン210D×15本×279 mm目×25掛×56目，2反
(ハ)　アミラン210D×15本×333 mm目×21掛×47目，1反
縁　編　アミラン210D×21本×0.5掛
口　編　アミラン210D×27本×0.5掛
○浮子棚　マニラ10匁左右各撚各1本
○沈子棚　サラン750D×81本×2×4子撚
○浮　子　桐×8寸×2寸×1.2寸×13枚，4反分
　　硝子球×3.5寸袋付×13枚，2反分
○沈　子　鉛×20匁×10コ，6反分
○縮　結　身網　浮子方　42 %
　　沈子方　44 %
　　添網　　55 %

以上の身網・添網を用い下記の如く各反を仕立てる。

A網

身網に添網(イ)を取付ける。

両網間隔を吊糸に適当箇所よりを連結し，この間隔を5寸とする。即ち，吊糸仕立上り長さ5寸である。

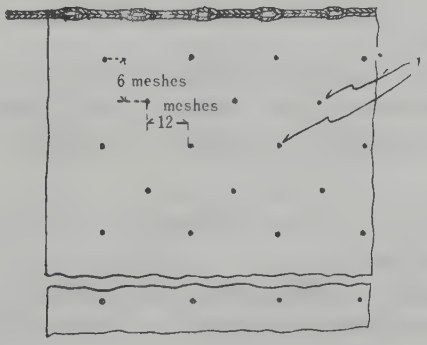


Fig. 1. The positions of pending threads arranged in triangle.
Note : 1 ···The positions of pending threads.

吊糸取付け位置並に配置は千鳥型式に配置し，添網縦方向間隔6目毎，横方向間隔12目毎に吊糸を取付ける。

浮子方両網取付方法は浮子棚を2本浮子棚式とし，各々に身網・添網を，硝子球は身網浮子棚・添網浮子棚間に挟まれるようにそれぞれ取付ける。

身網両側下辺の取付は両網間隔2寸に吊糸を取付ける。但し下辺沈子棚取付の吊糸は両網を一括結着して沈子棚に連結する。

B網

身網に添網(イ)を取付ける。

両網間隔2寸に吊糸を取付ける。

吊糸取付け位置は斜型式に配置し，添網縦方向間隔8目毎，横方向間隔16目毎に取付ける。

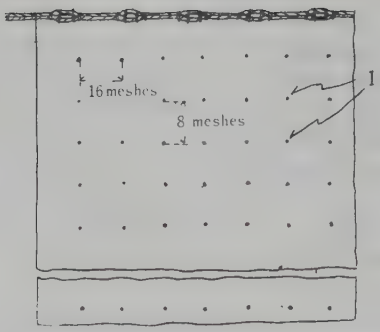


Fig. 2. The positions of pending threads arranged in square.
Note : 1 ···The positions of pending threads.

浮子方両網取付け方法は添網に目通し糸を通し，両網浮子方をかせ取付けにする。桐浮子を一般鮭鱒流網と同じく取付ける。

其他はA網に同じ。

C網

身網に添網(イ)を取付ける。

両網間隔2寸に吊糸を取付ける。

吊糸取付け位置並に配置は千鳥型式に配置し，添網縦方向間隔10目毎，横方向間隔20目毎に取付ける。

浮子方取付け方向は添網を身網の浮子方半目下に縫合する。桐浮子を一般流網と同じく取付ける。

身網下辺は沈子棚取付けの吊糸位置においても両網間隔2寸の吊糸を取付ける。

其他はA網に同じ。

D網

身網に添網(ロ)を取付ける。

両網間隔2寸に吊糸を取付ける。

吊糸取付位置と配置は桝型式とし，添網縦方向間隔5目毎，横方向間隔10目毎に取付ける。

浮子方両網取付け方法は身網・添網各々に浮子棚取付け2本浮子棚式とする。硝子球を2本の浮子棚間に挟むように取付ける。

E網

身網に添網(ハ)を取付ける。

両網間隔2寸に吊糸を取付ける。

吊糸取付位置と配置は千鳥型式に配置し，添網縦方向間隔3目毎，横方向間隔6目毎に取付ける。

浮子方両網取付方法は添網に目通し糸を通し両網浮子方をかせ取付けにする。桐浮子を一般流網と同じく取付ける。

身網下辺は沈子棚吊糸取付け箇所において両網間隔2寸に取付ける。

其他はA網に同じ。

F網

身網に添網(ロ)を取付ける。

両網間隔3.5寸に吊糸を取付ける。

吊糸取付位置と配置は桝型式に配置し，添網縦方向間隔7目毎，横方向間隔14目毎に取付ける。

浮子方両網取付方法は添網に目通し糸を通し，両網をかせ取付けにする。桐浮子を一般流網と同じく取付ける。

其他A網に同じ。

以上六種の構造の特殊二重網を作成し，当所地先海面において水中観察を試みた。

この時の海況は波高0－0.2—0.5 m程度，潮流流速0—0.5 浬/時，海水透明度良く水面下約4尋の網裾・吊糸・沈子棚の状況を明確に観察し得た。アクアラング・水中眼鏡を用い，随時潜水して得られた漁網の動態観察は次の如し。

I　海面静穏時の状態

（1）水中における身網・添網の網成りは共に屏風の如く垂直平面に展開されている。

（2）身網・添網網目共に所定の縮結の網目型に正しく均等に開いている。

（3）添網縮結55 %の網目型は魚体後部の纏絡が予想され，魚体游泳状態から特に横方向の纏絡が大きいことを考慮する必要があるから，横方向の縮結を大きくして横方向網地の余裕を見込む必要がある。即ち魚体羅網箇所に添網纏絡して襞を生じても添網網目型が30 %の縮結に止まる範囲においては 他魚の羅網には一応支障ないと推定されるからである。

この点からはかなり良好な縮結と思われる。添網7.4寸目は第5表に見られる如く，身網網目縮結43%のものに対し縦の網目長さ約2.0倍であるから，想定される魚体に対してかなり小さく感ぜられる。大体添網網目の縦の長さ約3.0～6倍位が適当である。単位面積当り網目数は大体次式で示される。

Table 5. Mesh size of main net compare to it of outer net.

Mesh size	mm	Shrinkage percent	Mesh length mm	Mesh width mm	Comparison of mesh: Mesh length	Comparison of mesh: Mesh width
Main net	121	43	100	69	1.0	1.0
Outer net	224	55	200	101	2.0	1.45
	279	55	248	126	2.5	1.80
	333	55	297	150	2.97	2.17

単位面積当り網目数……Mn.

網目の大きさ……m.

縮結……S.　とすれば

$$M_n \fallingdotseq \frac{1}{m\sqrt{1-(1-S)^2} \times m(1-S)}$$

Table 6. Total number of meshes on 1 hilo square.

Mesh size	mm	Shrinkage percent	Lateral meshes per hilo	Vertical meshes per hilo	Total meshes per 1 hilo square	Total meshes of main & outer net compare to it of main net percent
Main net	121	43	21.83	15.15	330.7	100
Outer net	224	55	15.02	7.58	113.8	134
	279	55	12.05	6.1	73.5	122
	333	55	10.08	5.1	51.4	116

Note : 1 hilo equal 1.51 meters.

第6表に示す如く，単位面積当りの網目数は 121 mm 目身網網目数に比べ添網 224 mm 目のものを取付け

た場合は134 % になり 333 mm目のものは116 % になるから一枚網地に比べ可成り可視されやすい。この漁網では大体120—115 % 以下にすることが1つの目標となろう。

以上の観点のみから見れば特殊二重網の魚体羅網状態の特長から添網は身網縮結に同じくし，添網網目を可及的に大きく決定することが良いことになる。

しかして添網縮結を30 %位にすることは羅網上の特色から 羅網魚一尾当りの添網網目変形範囲を大ならしめ，また魚体特に中央より後部の纏絡作用を減じ，羅網性能が低下するから好ましくない。

以上魚体羅網状態を予想した水中観察の結果であるが，添網網目の大きさと網目型は

(イ) 魚体が添網網目を潜りやすく纏絡しやすい網目の大きさと網目型であること。

即ち，添網網目を魚体が潜った状態を想定すれば第3図の様になり，

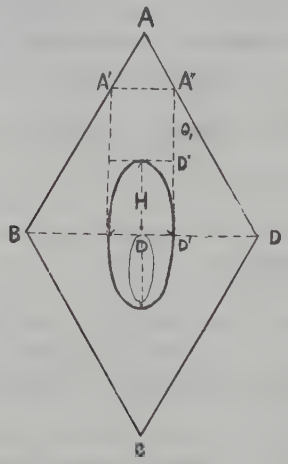


Fig. 3 (a). The relation of outer net mesh & section of fish body when the body incline in vertical to the mesh of it.
Note : H…Body height.
D…Body width.

Table 7. On total length, height and width of body with dog salmon, red salmon & pink salmon.

Species	Total length mm	Body height mm	Body width mm	Note
Dog salmon	624	139	59	Body width calculated by construction.
〃	585	152	65	Body width calculated by construction from the dimension of frozen dog salmon.
〃	589	152	65	do.
Red salmon	576	132	56	Body width calculated by construction.
Pink salmon	448	108	47	do.
〃	485	115	49	do.

この時魚体　体　高……H

魚体体高部厚さ……D　　とすれば

（a）魚体垂直方向に傾斜した場合

魚体体高部より上方向に A″D″＝ $\frac{H}{2}$ の高さに，体高部厚さ，DをA′A″にとり，このA′.A″を過ぎるAB.ADによってなす角Aが設定した縮結になるように網目型を作図する。（第3図(a)参照）

添網縮結50%にすれば　　∠A≒60°である。

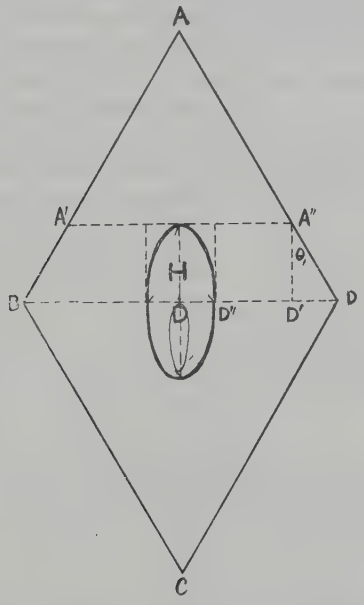


Fig. 3 (b). The relation of outer net mesh & section of fish body when the body incline in level to the mesh of it.
Note : H…Body height.　　D…Body width.

魚体頭部が軽く身網網目にかかった時，背鰭後端を添網がかわった位置までの距離L_D 303 mm，白鮭体高H＝139 mmとすれば，この時魚体が添網網目にふれるための最小傾斜角度は大約 $\sin\theta = \frac{\frac{H}{2}}{L_D}$ であるから $\theta \fallingdotseq 13°-30'$ である。この時の添網網目脚の長さは AD＝A″D′ × Cosec θ_1＋AA″＝221 mm，添網目は442 mm目になる。

羅網時の魚体は左右に屈折し，上下に傾いて離脱せんとするから，この時の上下方向の魚体傾斜角度が13°—30′になれば背鰭か腹鰭が添網網目に触れ羅網初期を構成すると推定される。

以上により魚体上下方向の最少傾斜角度15°なれば，添網網目は464 mm目になる。

（b）魚体水平方向に傾斜した場合

鮭鱒類游泳時は魚体の3/4以後が左右によく動く。しかし，この場合は添網が魚体に触れる位置は背鰭後端を標準にしており，羅網時の初期状態を想定するから魚体左右運動の傾きを最少 D″D′＝ $\frac{H}{2}$ として前項と同じく作図すれば添網網目縮結50%の時

$AD = A''D' \times \mathrm{Cosec}\ \theta_1 + AA'' = 280$ mm，添網網目561 mm目になる。この時の最小傾斜角度は 13°—30′である。

魚体最小傾斜角度15°とすれば

背鰭後部水平方向の動きは $D''D' = 79$ mmであり，添網網目597 mm目になる。

以上は白鮭を対照とした場合の私案として添網網目の大きさを決定した。

Table 8. On the mesh size of outer net shrinkage in 50 percent when body length is L_D and body is laid to the outer net in minimum angle.

Species	Dog salmon	Pink salmon
Dimension of fish body mm	L_D 303 H 139 D 78	L_D 227 H 112 D 48
Minimum angle in vertical to the net. $A''D'' = \frac{H}{2}$	13°—30′	14°—00′
Mesh size of outer net mm	442	324
Minimum angle in vertical to the net. A″ D″ Dog salmon 79 mm Pink salmon 59 mm	15°—00′	15°—00′
Mesh size of outer net mm	464	376
Minimum angle in level to the net. $D'D'' = \frac{H}{2}$	13°—30′	14°—00′
Mesh size of outer net mm	561	458
Minimum angle in level to the net. D′ D″ Dog salmon 79 mm Pink salmon 59 mm	15°—00′	15°—00′
Mesh size of outer net mm	597	467

Note : H…Body height.　　D…Width of body.

鰭の場合，垂直方向への最小傾斜角度14度の時は添網 324 mm目，15度の場合は376 mm目，水平方向最小傾斜角度14度の時は添網 458 mm目，15度の場合は 467 mm目になる。

言うまでもなく添網縮結，魚体羅網時の両網間に挟まれた魚体長と魚体最小傾斜角度の設定によって添網網目大きさが変ってくる。

また縮結後の身網網目に対し縮結後の添網網目縦の長さは3.0～6.0倍くらいが適当と思われる。

(ロ) 添網を身網に取付けることによって魚体から可視されがたい構成と設計にすること。即ち，この目的のためには構成上から見た添網は水中において網地にたるみのない垂直平面状に展開されるものである。この場合設計上からは前記 (3) に述べる如く単位面積当りの網目数が身網網目数に対し 20～15 %以下にする

ことがよい。

(ハ) 添網に魚体纏絡することによって襞を生ずるから網目変形範囲を考慮して縮結をかなり大にする方がよい。

以上(イ)(ロ)(ハ)の各項は添網網目決定上数値的にかなりのはばがあり，また相入れない条件をもっているから，結局現在のところ操業試験によって決定する外方法がない。

（4）両網の間隔は2本浮子棚式（A．D網）が最もよく開くが，浮子方に揚・投網時纏絡多く操業上思わしくない。その他の両網を浮子方に一括取付けたものは添網の方向から水流を受けた時，浮子方より下方100 cmくらいまで開きにくい場合が見られた。それ以下は少しの流速でもよく開き，網裾は一属よく開く。水流を添網側の反対から受けた場合両網間隔はなくなり，身網が添網網目にはみ出ることは決してない。水流なき時も同じ状態になる。しかし身網にちょっと触れれば容易に両網は開く。

この点両網間隔なき場合でも魚体を両網で挟む状態になる可能性が多い。

（5）吊糸を千鳥型式に取付け，吊糸位置適当で網成りよきものは，吊糸間のふくらみは水流 0.2～0.5 浬のときの身網吊糸間隔の1/3に対し縦方向，横方向共に5～15 %程度あり，最高20 %程度は殆んど見られなかった。このふくらみは網裾の方が大きい傾向がある。

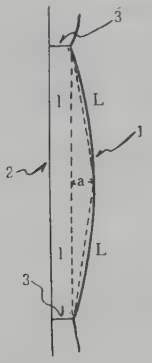


Fig. 4. The swelling of main net by stream when the positions of pending threads set in triangle on the outer net.
Note : 1 …Main net.
2 …Outer net.
3 …Pending thread.
a …The swelling of main net.
L …Half length of main net between two pending threads.
ℓ …Half length of the distance between two pending threads.

以上によって網裾吊糸2寸にとる必要はなく，身網下辺に添網下辺を直接取付けて支障ない。

両網間がよく開き，吊糸がかなり引張られている状態であっても，吊糸両網連結部を引き寄せ，特に身網網目型を変形することはなかった。但しC網は添網網目縦10目毎，横20目毎には水流強くあたった時多少この傾向が見られた。

吊糸仕立上り長さ152 mmのものは両網間が開いているとき浮子方に近きものはたるみ気味であった。従って浮子方に近き吊糸は普通間隔の約30～60 %増加すればよい。吊糸のたるみと，結着部の先端はバラケて水中において網糸に比べかなりよく目立つ。

（6）吊糸を枡型に取付けた B．D．F 網共にふくらみが浮子方から沈子方につながって，垂直方向に著しく生じた。水平方向のふくらみは殆んど認めることができなかった。ふくらみは吊糸間身網の長さに対して大きい時は20～25 %になる。身網地に当ってからの魚体游泳方向は水平方向に反転する率が多いから枡型式に取付ける場合，両網の関係を特殊に設定すればかなり興味ある吊糸配置であると思われる。

吊糸位置はふくらみが大きいため，吊糸連結部で身網網目変形が少しあるから千鳥型式のものに比べ，相対的に吊糸連結部を数本にして補強する必要を生ずることがあると思われる。

Ⅱ　波浪中に於ける状態

波高0.2—0.5 m程度における特殊二重網の水中における状態は，

(1) 波浪の山がくれば浮子方は浮子予備浮力が作用して衝撃時に浮き上る。この時浮子下身網・添網共に

網目両脚を片目増しに伝って瞬時に荷重がかかり，次にこの浮子直下の網地と沈子棚に連結した吊糸が衝撃的に引きあげられ，この時の吊糸連結部の網裾が浮子方上昇率の約半分くらいまで上昇するように観測された。波高低き時は浮子棚の上昇は網地に吸収され，沈子方は殆んど上下の動揺はしない。波浪の山が浮子方を移動するとこの移動速度に等しく吊糸が沈子棚を衝撃的に引揚げながら移動してゆく。

従って網目は波浪の山がくる度に縦方向に引き伸ばされる。この程度は吊糸部分の網目型の変形が著しい。浮子方は浮子棚に縮結によって一定に細目形が固定されているから比較的その変形は少ない。

(2) 波浪の谷がくれば浮子方は降下し，網地はたるみ気味になり，沈子棚はその沈降力によって波浪の山のきた時引き上げられた位置から沈降しつつある。沈子棚沈降力と速度と網地のたるみと浮子方の上下動揺の関係はかなり複雑な関係が予測される。

従って網地がたるみ気味になった時は網目型は横方向に伸びた型に変型する。この変型度合は浮子方・中間・網裾の各網地位置の順に従って大きくなる傾向がある。葉室は鮭鱒並に流刺網の水中における形状測定実験中にもこの傾向があると述べている。

(3) 身網，添網共に網丈は同長であるから波浪の度にほぼ同調して上下運動をする。もっとも精密に見ればかすかにずれがある。波浪の山が来て，網目脚の両側片目増しに衝撃的に荷重がかかる時に浮子方網目脚から片目増しに沈子方に連結する網目脚は小さく激しく瞬間的に振動し，網糸を二重三重に太く視覚させる。これは身網網目に著しく，浮子方に近い方が激しい。網目両脚片目増し間にはさまれた網地は荷重の伝導が直接的でなく，荷重が分割されて二次的に伝わるから，網糸自体の緩衝によって震動はあまり見られない。

沈子棚取付吊糸結着部の網裾は波浪度に激しく縦に引かれるから，この部分の網地網目は縦方向に変形され網目密度が大になり可視されやすく，網成を損じている。

(4) 両網間を連結する吊糸は大体予想の状態を示した。身網地下辺両側に取付けた仕立上り 61 mm の吊糸は波浪の度に網地に同調せず，揺れるから魚体の視覚にうったえやすく，直接両網を取付ける方がよいと思われた。

2　第二回試作特殊二重網

第一回試作特殊二重網の水中観察の結果を勘案し修正して第二回改良試作をおこなった。即ち，吊糸を千鳥型式配置により吊糸仕立上りの長さと取付位置の調整並びに添網縮結程度の決定に主眼をおいた。

身網添網共に第一回試作のものを利用した。身網縮結浮子方42 %，沈子方44 %，平均43 %に総て設定し添網縮結，吊糸仕立上りの長さ位置は第9表の如くした。

Table 9. The positions of pending threads on the outer net in case of setting points are triangular style.

Net No.	Mesh size of outer net mm	Shrinkage percent	Length of pending thread mm	Positions of pending threads on outer net	
				Vertical mesh	Lateral mesh
1	224	60	121	Each 4 meshes	Each 8 meshes
2	279	55	91	Each 4 meshes	Each 8 meshes
3	333	50	152	Each 5 meshes	Each 8 meshes
4	279	43	121	Each 3 meshes	Each 5 meshes
5	224	55	121	Each 6 meshes	Each 11 meshes
6	224	36	152	Each 4 meshes	Each 5 mesues
7	333	50	106	Each 5 meshes	Each 8 meshes
8	273	43	121	Each 7 meshes	Each 10 meshes

上表吊糸仕立上りの長さと吊糸位置の設定は次の如き計算方法によった。

I　千鳥型式吊糸取付け位置決定方法について

前述の如くこの方式による吊糸配置は身網添網間隔を最小吊糸数でほぼ均一に保つには最良の方式であると思われる。

対象魚体を鮭鱒類とした場合の吊糸位置設定方法を示せば次の如し。

鮭鱒類中主要魚種の白鮭，紅鮭，鱒の各部魚体寸法を第10表に示す。

Table 10. On the body dimension of genus *Oncorhynchus*.

Species		Dog salmon	Dog salmon	Dog salmon	Red salmon	Pink salmon	Pink salmon
Total length	mm	624	585	579	576	448	485
Head Length	mm	118	106	121	△109	△ 87	× 104
Body height	mm	139	152	152	△132	× 108	× 115
Snout to the origin of pectoral fin	mm			106	115		
Snout to the tip of pectoral fin	mm			167	158		
Snout to the aft insertion of dorsal fin	mm	× 364	351	315	△303	× 248	× 268
Girth at the part of body height	mm	○346	351	382	○327	○267	○285
Body width	mm		○ 65	○ 65	○ 56	○ 46	○ 49
Note		By M. Katayama. Measured frozen dog salmon by T. Watanabe. do.					

Note : Mark　△…Calculated from the measurement of dog salmon.
× …Calculated from the figures of genus *Oncorhynchus*.
○…Calculated from the construction of fish body section.

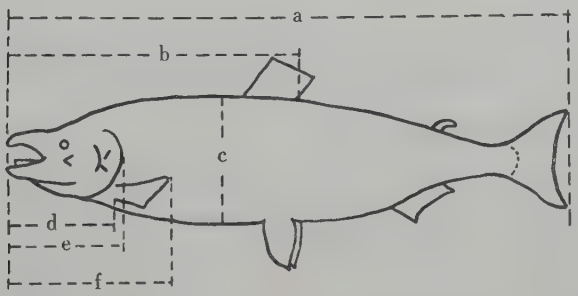


Fig. 5. Show the measurement positions of fish body.
Note: a …Total length of body.
b …Snout to the aft insertion of dorsal fin.
c …Body height.
d …Snout to the origin of pectoral fin.
e …Head length.
f …Snout to the tip of pectoral fin.

上表は生物学的測定としては多少不満足なものであるが，本漁網設計に当っては実用上さしつかえない。

先ず吊糸仕上りの長さは魚体が添網網目を潜って身網に当らんとしたとき，少くとも胸鰭後端が添網網目を通過していることが望ましい。白鮭の吻端から胸鰭後端まで167 mmとすれば，この頭長約118 mmの穴が身網網目に刺さっておるとすれば，身網網目から胸鰭後端までの間隔は128 mmになる。吊糸仕立上りの長さは吊糸間の身網地のふくらみと羅網時魚体が身網を押すことを考慮して大体91～152 mm位に決定すればよいと思われる。

吊糸取付箇所は構成と設計条件に合う限り最小数がよい。水流0.2～0.5浬の範囲であればふくらみは5～20 %であり，一般には15 %止まりである。

即ち，身網吊糸間隔　　2L

吊糸間の間隔　　2ℓ

身網地のふくらみ　　aとすれば（第4図参照）

$$\frac{a}{L}\times 100=10\text{—}15\text{—}20\ \%$$

この時の $\frac{L-\ell}{L}\times 100=0.5\text{—}1.1\text{—}2.0$ %になり，極めて小さい吊糸間の縮少によって，かなりのふくらみaを生ずる。

次に魚体が身網網目に軽く頭部を刺し，魚体反転運動の時，添網網目糸に魚体の触れる位置は大きくて背鰭後方をかわった位置あたりが望ましい。

この位置は背鰭，腹鰭が突出しているから添網が纏絡しやすい。尾鰭の位置では添網が広い範囲に纏絡する傾向が大きく，添網網目型をこわす面積が過大になると推定され，また魚体取外しにより多くの労力を要求されるからである。

上述によって身網吊糸間隔を決定すれば，

即ち，魚体頭部穴後方より背鰭後端までの長さ　　L_D

吊糸仕上りの長さ　　r

身網吊糸間のふくらみ%　　a

身網吊糸間隔　　2L

とすれば，

$$\frac{(L_D-r)}{a}\times 100=L$$

で示される。

実用的にはふくらみaは身網に魚体が当って添網にかかる前に身網を押し進める傾向があるから，安全率をとって22～24 %にした。

上述計算式によって吊糸位置を下記の如く決定した。

●No. 1 試作網

頭部穴後方より背鰭後端までの長さ　L_D…303 mm

吊糸仕立上りの長さ　r……121 mm

身網吊糸間のふくらみ　a……24 %

とすれば，L＝758 mm

添網224 mm目縮結60 %にすれば

添網縮結後の網目縦の長さ $m\ell$……206 mm

横の長さ mb……90 mm

千鳥型式の場合は添網縦方向の網目＝$\frac{L}{m\ell}$＝3.65目≒4目

横方向の網目＝$\frac{L}{mb}$＝8.40目≒8目

即ち，添網縦方向に4目毎，横方向に8目毎に吊糸位置を設定した。

●No. 2試作網

添網 279 mm 目　縮結55 %

添網縮結後の網目縦の長さ m ℓ …… 248 mm

横の長さ m b …… 125 mm

吊糸仕立上りの長さ 91 mm，身網吊糸間のふくらみ a …22 %，

吊糸位置は

縦方向 $\frac{L}{m\ell}$ =3.85目≒4目毎

横方向 $\frac{L}{mb}$ =7.65目≒8目毎

●No. 3試作網

添網 333 mm 目　縮結50 %

添網縮結後の網目縦の長さ m ℓ …… 290 mm

横の長さ m b …… 167 mm

吊糸仕立上りの長さ 152 mm，身網吊糸間のふくらみ a …22 %

吊糸位置は

縦方向 $\frac{L}{m\ell}$ =2.38目×2倍≒5目毎

横方向 $\frac{L}{mb}$ =4.12目×2倍≒8目毎

●No. 4試作網

添網 279 mm 目　縮結43 %

添網縮結後の網目縦の長さ m ℓ …… 230 mm

横の長さ m b …… 159 mm

吊糸仕立上りの長さ 121 mm，身網吊糸間のふくらみ a …22 %

吊糸位置は

縦方向 $\frac{L}{m\ell}$ =3.3目≒3目毎

横方向 $\frac{L}{mb}$ =4.75目≒5目毎

●No. 5試作網

添網 224 mm 目　縮結55 %

縦網縮結後の縦目の長さ m ℓ …… 200 mm

横の長さ m b …… 102 mm

吊糸仕立上りの長さ 121 mm，身網吊糸間のふくらみ a …22 %

吊糸位置は

縦方向 $\frac{L}{m\ell}$ =3.75目×1.5倍=5.6目≒6目毎

横方向 $\frac{L}{mb}$ =7.45目×1.5倍=11.2目≒11目毎

●No. 6試作

網添網 224 mm 目　縮結36 %

添網縮結後の網目縦の長さ …… 172 mm

横の長さ …… 141 mm

吊糸仕上りの長さは 152 mm，身網吊糸間のふくらみ a ……22 %

吊糸位置は

縦方向 $\frac{L}{m\ell}$ =4.0目毎

横方向 $\frac{L}{mb}$ =4.85目≒5目毎

●No. 7 試作網

添網 333 mm目　縮結50 %

添網縮結後の網目縦の長さ 290 mm

横の長さ 167 mm

吊糸仕立上りの長さ 106 mm，身網吊糸間のふくらみ a …22 %

吊糸位置は

縦方向 $\frac{L}{m\ell}$ =3.07目×1.5倍=4.6目≒5目毎

横方向 $\frac{L}{mb}$ =5.35目×1.5倍=8.05目≒8目毎

●No. 8

試作網添網 273 mm 目　縮結43 %

添網縮結後の網目縦の長さ 224 mm

横の長さ 155 mm

吊糸仕立上り長さ 152 mm，身網吊糸間のふくらみ a …24 %

吊糸位置は

縦方向 $\frac{L}{m\ell}$ =3.4目×2倍=6.8目≒7目毎

横方向 $\frac{L}{mb}$ =5.85目×2倍=9.7目≒10目毎

以上8種類の試作網の水中観察を再度試みた。この結果は大体下記の如し。

Table 11. Total number of meshes per 1 hilo square.

Net No.	Mesh size mm	Shrinkage percent	Lateral meshes per hilo	Vertical meshes per hilo	Total meshes per hilo square	Total meshes of main & outer net compared to it of main net percent
Main net	121	43	21.81	15.15	330.7	100.0
Outer net 1	224	60	16.91	7.4	125.1	137.8
2	279	55	12.05	6.1	73.5	122.2
3	333	50	9.1	5.29	48.1	114.5
4	279	43	9.5	6.6	62.7	119.0
5	224	55	15.02	7.58	113.8	134.4
6	224	36	10.7	8.8	94.2	128.5
7	333	50	9.1	5.29	48.1	114.5
8	273	43	9.75	6.78	66.1	120.0

(1) 単位面積当り網目数は添網をとりつけたことにより第11表の如くなり，No. 1，No. 5，No. 6，No. 2，No. 8 は比率において120 %を越え，魚より可視されやすい点において難点があると思われる。水中観察において No. 1，No. 5 はかなり網地が目立って感じられる。No. 3，No. 7 は約114 %で身網に

対し添網の目立ち方は甚だしく薄らぐ。添網網目は潜りやすい目の大きさと網目型を要求されるのが第一条件であるが，これは第二章に述べる如く添網網目面積と網目型と魚体の大きさ，魚の運動を勘案して各要素を決定し，波浪のために生ずる添網の特に上下動揺速度と振巾を考慮に入れて網目型は縦方向を大きく決定すべきである。しかし添網60 %の縮結は水中における網目型から縮結が過大であると思われた。即ち，縮

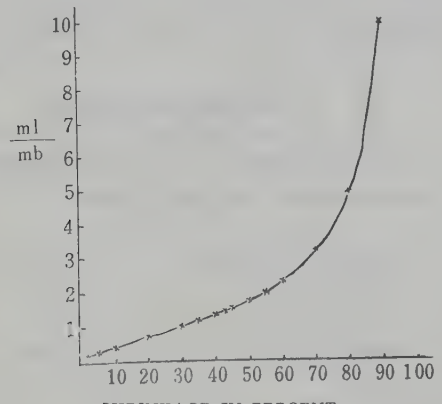


Fig. 6. The ratio of length & width of mesh in the shrinkage.
Note : ml …mesh length in the shrinkage.
mb…width of mesh in the shrinkage.

結後の網目縦方向の長さm ℓ，横方向の長さをm bとすれば，

$\frac{m\ell}{mb}$ =2.0～1.5の範囲で縮結に換算すれば56～45 %位になる。魚体運絡時添網の縮結50 %なれば$\frac{m\ell}{mb}$ =1.72で，横方向の余裕はかなりあると観測された。

(2)' 吊糸仕立上りの長さは前述の如く91 mm～152 mmでよい。

(3) 千鳥形式吊糸位置は身網のふくらみと吊糸附近の襞を生ずる関係から水流0.2～0.5浬の範囲では鮭鱒を対象とする場合は身網吊糸間隔は121～152 cmの範囲が適当であると思われた。

即ち，

吻端から頭部乃後方から背鰭後端までL_D…303 mm

吊糸仕立上りの長さr.…106 mm

$\frac{(L_D - r)}{L} \times 100 = 121 \sim 152$ cmとすれば

a =16.25～15 %になり

$\frac{L-\ell}{L} \times 100 = 1.4 \sim 1.1$ %

以上の程度が実用的ふくらみ（a）と見てよいと思われる。

(4) 浮子方と最上部吊糸間の身網網実は添網に対し身網網目半目～1目大きくして網成りは支障なかった。波浪による身網添網の上下動揺同調の問題は波浪0.20～0.60 mの範囲では小さかったので，はっきり判定できなかった。この程度では大体良好であった。

(5) 添網網目周囲の大きさ決定については，

白鮭の体高139 mm，この位置における魚体周囲 G_{BH} は作図によれば，345 mm

添網縮結50 %とすれば

添網網目周囲 M_G＝（2～4）×G_{BH}，

即ち，M_G＝691～1382 mm程度が一応の目安になる。

実用的には添網網目の中に身網網目が縦方向に3～6目位の網目長さに合致させるように決定するのが便利であると思われる。

なお，Ⅱ.1，I(3) (イ)の添網網目大きさの計算方法を参照すれば大体決定できる。

Ⅲ　1957年鮭鱒流網試漁成績

1957年7月上旬より8月上旬にかけて釧路根拠第十一福寿丸で小規模な操業試験を実施した。

これに用いた特殊二重・三重流網の設計概要と使用反数は下記の如し。

1　身　網

アミラン210D12本，115 mm目53掛60.6 m切れ，10反

縁編　18本，24本，36本（79 mm目）各半目

口編　27本半目36本飛目

(1) 棚　糸　上棚マニラ10匁右，左撚各1本.　下棚マニラ20匁右，左撚各1本

(2) 浮　子　合成浮子　45枚

(3) 沈　子　鉛20匁　40箇

(4) 身網縮結　浮子方42 %，沈子方44 %.

2　添　網

(1) アミラン 210D15本 327 mm目18掛216.5目，5反

(2) 同　上　333 mm目18掛204.5目，5反

(3) 同　上　339 mm目18掛190目，5反

添網上・下辺縁編36本半目で身網縁編長さに合わし，上辺はかけ合わして取付け，下辺は沈子網取付け吊糸部のみ両網を結着，その他は側面共に吊糸仕立上り61 mmに連結する。

添網網目1目に対し身網網目3目の割合に添網網目寸法を決定した。

その他は一般鮭鱒流網に同じ.

3　仕立上り反数

A　特殊二重流網

身網に添網(1)を取付けたもの，5反

B　特殊三重流網

身網両側に添網(2) (3)を取付けたもの，5反

(1)　吊糸仕上立りの長さと取付位置

A網は縮結50 %で身網に取付け，吊糸仕立上り長さ106 mm，吊糸配置千鳥型式とし，

吊糸位置は添網網目

縦方向4目毎，横方向7目毎のもの，3反

縦方向5目毎，横方向9目毎のもの，2反

B網は添網 (2) 縮結48 %，(3) は45 %，

吊糸仕立上りの長さ，配置共に同じ。

吊糸位置は添網網目

縦方向4目毎，横方向7目毎のもの，3反

縦方向5目毎，横方向8目毎のもの，2反

上記特殊二重・三重流網の操業実績は下記の如し。

試漁方法は一重流網・特殊二重流網・一重流網・特殊三重流網・一重流網の順に各反を連結し試験網関係合計20反，これを総使用反数のなるべく中間に連結し，日々各反当り羅網尾数を調査した。

当初多少懸念された投・揚網作業に関し，乗組員から労力過重される苦情はさしてなかった。最も懸念された羅網魚体の取外し作業は，魚種鰺であったが，特殊二重流網は引抜いて取外しできる程度で，一重流網と比較し多少手数を要する程度であったが，慣れるとともに問題は解消した。特殊三重流網は特殊二重流網に比べ羅網状態が少し複雑であり，取外し労力を少し多く要するが，慣れるとともに揚網作業時間に影響を及ぼすとはいわれなかった。

以上から，作業上から見た損失は，これら漁網取扱に習熟するとともに殆んど考慮する必要がないと思ってさしつかえない。

操業実績は第7図第12表より，

Table 12. Mean catch per day by the diffrent kind of drift nets.

Data		Daily mean catch		
		Single net	Double nets in specific construction	Three skeets net in specific construction
July	8	4.8	6.8	3.4
	9	3.6	4.6	2.0
	10	3.0	2.25	3.25
	24	0.8	0.8	1.80
	25	1.6	3.6	2.80
	26	0.3	0.8	0.80
	27	1.6	1.6	1.60
	29	2.4	3.8	1.40
Total		19.1	24.25	17.05
Mean		2.39	3.03	2.13
Percent		100	126.8	89.2

投網回数8回，反当り平均羅網数は，

一重流網　　2.39尾

特殊二重流網　3.03尾

特殊三重流網　2.15尾

一重流網反当り平均羅網尾数100 %とすれば，特殊二重流網26 %多く，特殊三重流網は11 %羅網尾数が少なく，三重網の羅網尾数少なきは極めて注目すべきである。

なお，7月7日の各反羅網尾数は，

一重流網14尾（漁撈長の概算）

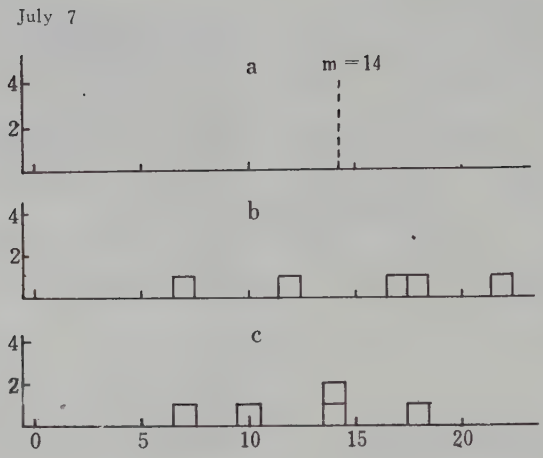
特殊二重網15.6尾（各反別の実績）

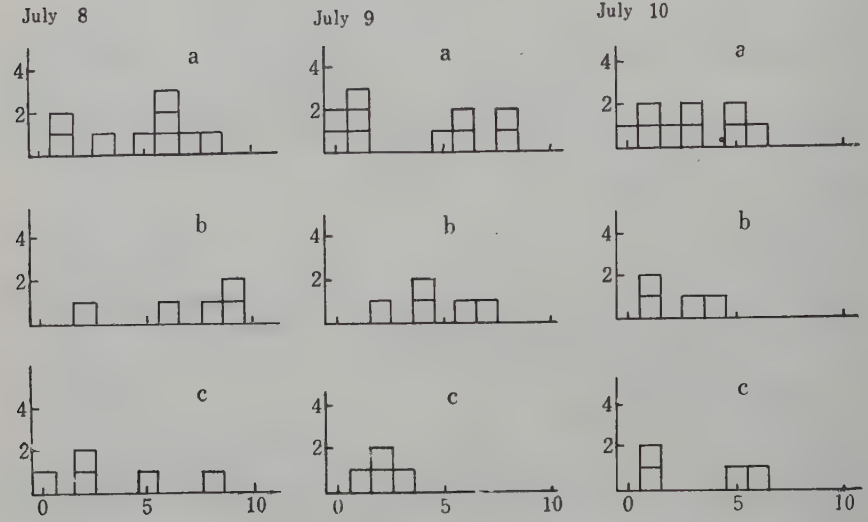
特殊三重網12.6尾（同上）

羅網尾数かなり多い時においても特殊二重流網が一重網に比べ約11.4 %多く最良の成績であることは興味深い。

以上の結果から大体決定されることは，

（1）　千鳥型式吊糸配置では吊糸間隔は


July 7
a
m = 14
b
c
4
2
0
5
10
15
20


July 8
July 9
July 10
a
b
c
4
2
0
5
10

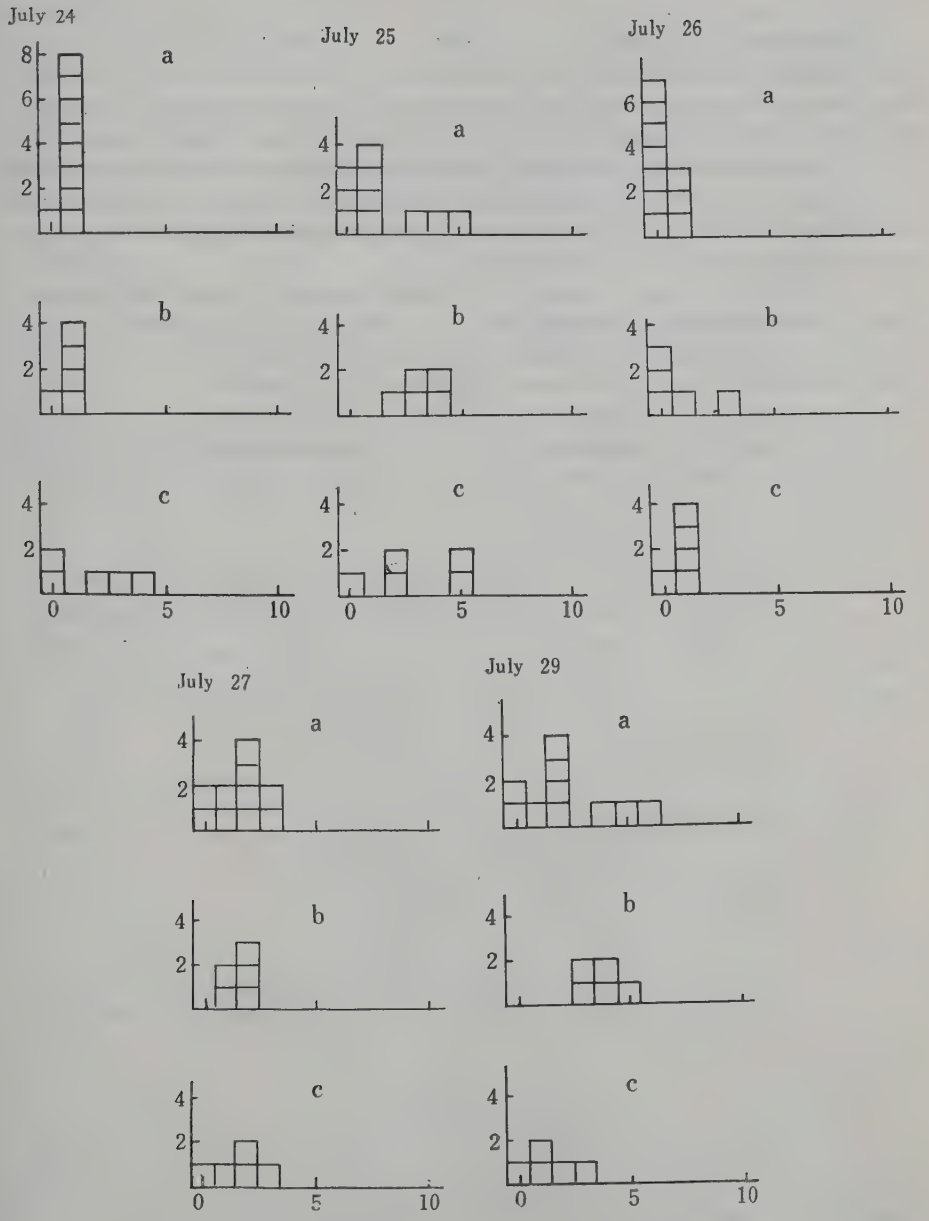


Fig. 7. Daily catch of each box in different structure.
Note : X—axis···Catch of each box. Y—axis···Number of box.
m ···Mean catch. a ···Single net.
b ···Double nets in specific construction. c ···Three sheets net in specific construction.

A網 縦方向4網目毎，横方向7目毎
縦方向5目毎，横方向9目毎
B網 縦方向4目毎，横方向7目毎

縦方向5目毎横方向8目毎で，大体支障は認められない。吊糸箇所は可及的少なくする方が網地が可視されにくく，漁網仕立費を軽減できる。羅網状態は確実で揚網中はずれることはないと判定される。

（2） 羅網状態は写真判定でも明瞭であるが，特殊二重流網では添網を潜って羅網したものは多く身網網目に頭部胸鰭がかかり，添網網目は胸鰭と背鰭の間または背鰭少し後方の範囲にあり，背鰭後部に網糸跡がつくほど纏絡せず網捌きによって直ちに外れる程度で，設計計算の羅網状態にほぼ近似である。網目変形範囲は一重網約 1.0M² に対し1.0～1.3M² 程度である。

（3） 特殊二重流網で身網の方から羅網したものは身網網目に頭部胸鰭または胸鰭，背鰭の中間程度まで刺さり，反対側の添網網糸に多く鰓蓋胸鰭をかけておった。網目は変形範囲は約 1.0M² 位で，(2) に比べ少し狭く，一重網とほぼ同程度であり，一重流網に比べ羅網状態は確実である。(2)，(3)の羅網状態は共に魚体取外しは少し手数を多く要すると思われる程度で，揚網作業時間には全然影響ない。

（4） 特殊一重流網は(2)，(3)の羅網状態の複合になるから少し複雑な纏絡状態になる。しかし網地を展開すれば，かなり複雑なものでも背鰭後部は直ちに出る。魚体の纏絡網糸跡は背鰭附近までである。魚体取外しは一重流網に比べ複雑であるが，習熟すれば問題なくなり，揚網時間を多く要することは殆んどない。

Table 13. Total number of meshes per 1 hilo square.

	Net		Lateral meshes per hilo	Vertical meshes per 1 hilo	Total meshes per 1 hilo square	Total meshes of outer net compare to it of main net
	Mesh size mm	Shrinkage percent				percent
Main net	115	43	23.04	16.03	369.3	100
Outer net	327	50	9.26	5.38	49.8	15.3
〃	333	48	8.74	5.31	46.4	12.6 } 24.4
〃	339	45	8.12	5.35	43.4	11.8 }

Table 14. On the difference of daily catch by the sort of drift nets.

Date		Difference of catch		
		Single net	Double nets in specific construction	Three sheets net in specific construction
July	7	—*	14	12
	8	9	8	9
	9	9	6	3
	10	7	4	6
	24	2	2	5
	25	6	3	6
	26	2	4	2
	27	4	2	4
	29	7	3	4
Total		46	32	39
Mean		5.75	4	4.875
Percent		100	69.5	85.0

*The data of single net is none, so the calculation of this table is not included.

網目変形度合は約1.3～1.5M² である。

（5）　羅網尾数率は一重流網100に対し，二重流網126%，特殊二重網89%で，特殊二重流網が最もよく有効であることを示し，特殊二重流網の理論的漁網構成は魚体が添網を潜れば，最も確実に捕えられるはずであるから，羅網尾数は多くなるが，この三重流網においては羅網尾数は少い。この原因は今のところ魚体から可視されやすい漁網であると判定する外ない。即ち，第13表に見る如く身網網目数に対し124%の網目数となり，より可視されやすい数値を示している。特殊二重流網は115.3 %で，羅網尾数から見て，この程度の増加は一応さしつかえないものと推定してよいと思われる。

（6）　一回投網毎に各反当り羅網尾数差について8回操業の投網一回当り尾数差平均値を見るに

一重流網　　5.75（100）

特殊二重流網　　4.00　(69.5)

特殊三重流網　　4.875（85.0）となり，有意差一重流網に比べ特殊二重流網の羅網尾数差大なる回数について見るに

$N=8 \quad K=1 \quad P=\frac{1}{2}$（従って $q=\frac{1}{2}$）

$n_1=2(K+1)=4$

$n_2=2(N-K)=14$

$Fs=\frac{n_2P}{n_1q}=3.5$であるから

$F_S=3.5>F^4_{14}(0.05)=3.11$

であり，同じく特殊三重流網については

$F_S=3.5>F^4_{14}(0.05)=3.11$　である。

特殊二重流網に比べ，特殊三重網の羅網尾数少なき回数については

$F^6_{12}(0.2)=1.72<F_S=2<F^6_{12}(0.05)=3.00$　である。

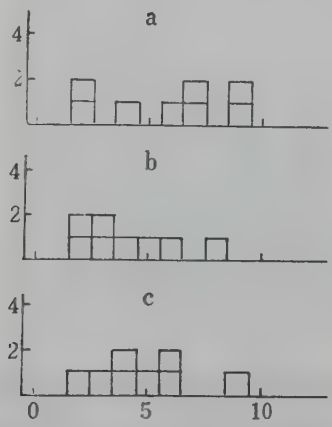


Fig. 8. Difference of daily catch of each box in different structure.
Note : X—axis…Difference of daily catch of each box.
Y—axis…Number of box.
a …Single net.
b …Double nets in specific construction.
c …Three sheets net in specific construction.

頻度分布大きいため，そのうちより多くの Data を得て検討するつもりである。

以上によって一重流網が羅網尾数差大であり，特殊二重流網は最少で明瞭な格差を認めることができる。

羅網尾数差は魚体羅網時漁網に近づき又は網地に触れたものが恐怖して逃げる時浮子方方向の彎曲度合等によって網成りに変化を生じ，羅網しやすい網成り場所に多くかかる傾向を生ずるためと思われる。

魚群がほぼ平均密度で来游すると仮定すれば，一重網はこの傾向を多く生じ，特殊二重流網は網地に近づいた魚体がそのまま羅網する率が多いことを示し，特殊三重流網は一応の推定として魚体に網地を可視される率多く，一重流網の如く網成りによって羅網しやすい位置に集まる傾向多くなり，この関係から羅網率は低下するが，一重流網に比べ羅網尾数差少なきは添網を潜った魚体はかなり逃げ難いと判定される。

Ⅳ　流網関係の新考案について

本研究にあっては主として次の三項目の新考案について，かなり研究がすすめられた。これらの新考案を要約すれば次の如し。

1＊　特殊二重流網の構成

図面に示すように，身網(1)の片側にほぼこれと同巾の大きい網目の添網(2)をそわせ，両網(1)，(2)の浮子方を縫合(4)し，身網(1)と添網(2)とは数段にわたり両網(1)，(2)間に適当な間隔を有するように吊糸(3)又は縫合で連結した流網であることを特徴とする。

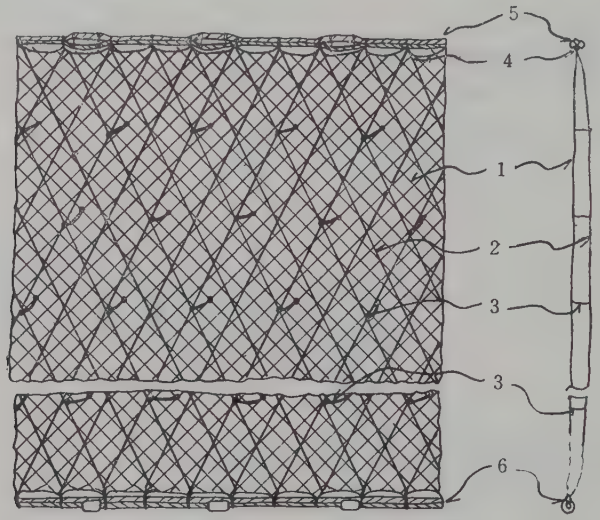


Fig. 9. The double nets in special construction.

即ち，身網(1)網丈に対し添網(2)網丈を大体同長前後か少し長目にし添網(2)浮子方を身網(1)浮子方に取付け身網(1)網目に対し添網(2)網目は大きいから，水流抵抗差によって両網(1)，(2)が開くから，この間隔を比較的均一に保つように，例えば吊糸(3)によって両網(1)，(2)間を連結して調整する。従って添網(2)網目を潜った魚体は身網(1)網目に刺さると同時に魚体運動によって添網(2)網目脚が纏絡して捕われる。即ち魚体に対し同時に二枚の網地(1)，(2)網目が作用して羅網ずる。

＊ 特許出願公告昭34—8332　流網　出願人発明者　渡辺享　公告昭34.9.17

2*　沈子方に緩衝装置をつけた流網

網裾(1)に三角網(2)を取付け，三角網(2)の下方頂点附近にゴム，ゴムを用いた紐，合成樹脂，合成樹脂を用

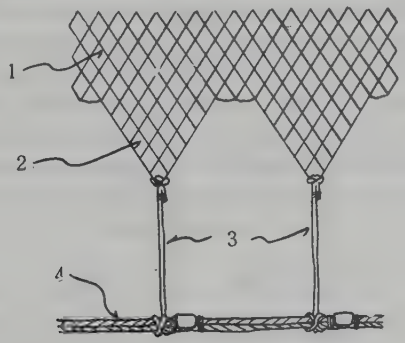


Fig. 10. Norsels apply the device of buffer.

いた紐，金属性スプリング，その他のものを用いて弾性限界を大きくした吊糸(3)又は前記吊糸(3)に在来の吊糸を連結し，その下端を沈子綱(4)に連結した装置を有する沈子方に緩衝装置をつけた流網

即ち，波浪により流網網裾(1)が上下動揺せしめられるから網裾(1)に三角網(2)を取付け，その下端に弾性体(3)を取付け，沈子綱(4)に連結すれば，弾性体(3)により上下動揺をある程度吸収し，この時網裾(1)に作用する力作用を三角網(2)によって広い範囲に分散せしめ得るから，沈子方の安定と網成りの変形を或る程度防止することができる。

3　浮子方に補助浮子を取付けた流網**

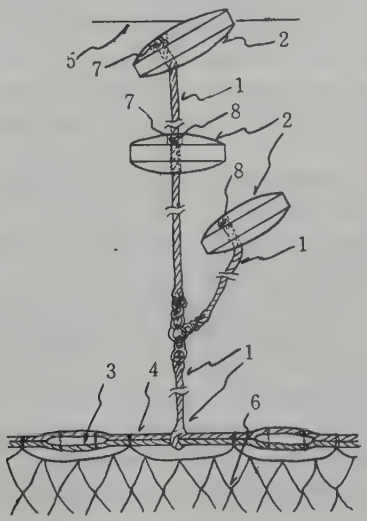


Fig. 11. The drift net set the auxiliary floater to neutralize the shock of concussion.

* 特許出願公告昭34－5719，沈子方に緩衝装置をつけた流網　出願人発明者　渡辺　享　公告34.6.30.
**実用新案登録番号　第497532号　流網　出願人考案者　渡辺　享　実用新案出願公告　昭34－5764，公告　昭34.4.21.

図面に示すように流網の浮子(3)を有する浮子綱(4)の適宜箇所に補助浮子綱(1)を設けて，これに適数の補助浮子(2)を多段的且つ移動調節自在に設けた流網の構造である。

即ち，例えば浮き流網浮子(3)浮力は予備浮力を充分もつように設計されているから，波浪の上下動揺によってこの(3)予備浮力が作用するから，浮子方を激しく上下動揺して網地(6)の安定をこわし，網成りを悪化する。これを防止する目的で浮子(3)浮力を小さくして浮き流網浮子方がようやく浮ぶ程度に調節し，不足する予備浮子を補助浮子綱(1)を設けこれに補助浮子(2)を多段的に取付けて補うようにすれば，浮子(3)浮力と補助浮子(2)浮力が波浪の上下動揺に従って段階的に作用するから流網身網(6)の安定を良好な状態に維持せしむることができる。従って補助浮子(2)に浮き流網に必要な予備浮力を従来のものに比べより大きく設定することができるから，魚類が多量に羅網し，また，網地(6)の縺絡等による漁具の沈下流失等を防止しうる。

V　摘　　要

母船式鮭鱒漁業において実質上の流網使用反数制限対策として操業能率を低下せしめることなく，羅網率を増進する漁網即ち特願昭和32年第19065号流網を主な研究対象として，これを一重，二重網として実用価値を確めんとした。

(1)　母船附属独航船の作業能率上特に影響を及ぼす揚網速度を一重網に比べ最大約30 %まで低下，即ち，29 m/sec. 以下の揚網速度は絶対に許容し難いとした。従って漁網操作上一重網に比べ，さして遜色ないものが要求されるとし，特に網捌きしやすい構成であること。

(2)　特殊二重流網の羅網方法として，添網を潜った魚体が身網網目に触れると同時に，添網網糸に触れて羅網する漁網であることを特色とし，これが構成と設計要素を決定せんとした。

(3)　(1),(2)を満足さす漁網構成として身網，添網共に浮子方沈子方の縮結のみとし，二枚の網地がほぼ垂直平面に重なる状態にした。身網アミラン210D，15本，121 mm目，添網アミラン210D，15本約303 mm目位のものであれば，水流0.2～0.6 浬の低速で両網地の抵抗差でよく開く。

(4)　添網網目は魚体が潜りやすく，且つ縺絡しやすく羅網による網目変形範囲を極力小さくすることが要求される。添網網目の大きさは特定の縮結に対し魚体高Hと，体高部の周Dと身網添網間に挟まれる魚体長Ld と魚体運動により想定される水平・垂直各方向の最小傾斜角度を与え，作図により或る程度決定される。

添網網目縮結は網目型より見て縮結後の網目縦横比は2.0～1.5で，縮結56～45 %になり，縺絡後の網目余裕を見て実用的には50 %前後がよいと思われる。

添網網目周囲の大きさは魚体周囲から見れば2～4倍の程度であり，漁網仕立上から見れば，縮結された身網網目縦の長さの3～6倍程度の添網網目が適当である。

(5)　吊糸配置と仕立上りの長さについては両網地間隔を平均に保ち，取付け箇数最少になるのは千鳥型式であり，吊糸仕立上りの長さは魚体吻端より頭部背から胸鰭後端までが適当であり，白鮭では121 mm前後であるから吊糸仕立上りの長さは106～152 mm位がよい。

吊糸間隔は身網のふくらみを本試験の漁網では安全率を見て千鳥型式の場合は20 %位まで，梯型式のものは25 %位までと推定し，羅網状態から離めた千鳥型式のものは実用的には15 %前後である。従って吊糸間隔はこの種鮭鱒流網では121～152 cm でよい。

浮子方は身網ふくらみは少なく網裾の方は大きいから，浮子方に最も近い吊糸は縦方向間隔は30～60%大きく設定するがよい。

(6)　二重網・二重網は魚体に可視されやすい欠陥が認められるから，本試験漁網程度のものなれば，一重網のものに比べ網目数は少くとも120 %以下に定める方が適当である。

(7)　1957年釧路根拠第11福寿丸試漁羅網成績は一重網100 %に対し，二重網126 %，三重網89 %で，二

重網が最もよい。

操業回数毎羅網尾数差は一重網100 %に対し二重網69.5 %，三重網85 %で，二重網が明らかに最も少なく，魚群来游頻度を各反毎に一定とすれば，羅網性能が最もよいことを示す。三重網は一重網に比べ少ないから，網地に触れた魚体に対しては羅網性能良好と思われるが，羅網尾数少なきは現在のところ魚体に可視されやすい流網であると推定せざるを得ない。この点二重網網目数は一重網100 %に対し115.3 %であり，可視されやすいために羅網尾数低減は今のところ認められない。

（8）　羅網状態は添網網糸が背鰭附近に止まっており，設計時魚体の予定網絡位置とほぼ一致した結果になっている。網糸による魚体損傷は一重網に比べ甲乙殆んどない。魚体の取外しは慣れれば二重網は一重網とほぼ同じ程度の作業時間と思われ，現場において問題にするほどのものではなかった。三重網は労力を少々要せられるようであるが，これまた作業時間の影響は少ないと判定される。

（9）　魚体羅網による網目変型範囲は，鰐一尾当り一重網約1.0M²，二重網1.0～1.3M²，三重網1.3～1.5M²と思われる。後続魚体の羅網に影響すると思われるほどの差異はない。

（10）　特殊二重・三重網は一重網に比べ漁網構成が複雑であるから，波浪中の網目の安定，棒網予防対策を考究する必要がある。この問題に対しては

(1) 実用新案登録　昭和34年第497532号　流網
(2) 特許出願公告　昭和34—5719号　沈子方に緩衝装置をつけた網流公告　昭34.6.30
(3) 実願昭33—42969号　流網
(4) 特願昭34—13403号　漁網
(5) 特願昭34—16684号　網地に緩衝浮力体を有する漁網

以上を研究の対象としておる。

終りに臨み，本研究実験のために，板村・藤原各教官，日本漁網坂根氏並びに学生溝口君以下数名の援助を受け，参考文献の多くは吉田・鶴田・松井各教授，統計に関しては前田教官から，釧路における試漁に関しては極洋捕鯨牧北海道支社長のあっ旋により実施することができた。ここに深甚なる謝意を表す。

文　　献

1）長棟　暉友：1933．最新漁撈学．厚生閣．
2）田口喜三郎：1957．北洋の鮭鱒漁業とその資源．日魯漁業株式会社．
3）佐野誠三，久保達郎：1946．北海道各河川遡上鮭（*O. keta*）の生態調査Ⅰ．水産孵化場試報，**1**(1).
4）片山　正夫：1934．鮭の生物測定学的研究．日水誌，**4**(3).
5）JOHN. N. COBB：1930. Pacific Salmon Fisheries. U. S. Department of Commerce Bureau of Fisheries, Fisheries Document **1092**. U. S. Goverment Printing Office. Washington.
6）葉室　親正：1956．鮭鱒流刺網の水中における形状測定実験について．漁船研究技報 **8**．
7）*Fishing News*：1958. Flint Salmon Men Use Trammels. Mar. 21. London.
8）R. GRAUMONT and E. WENSTON：1948. Fisherman's Knots and Nets. Cornell Maritime Press, New York.
9）渡辺　　享：1959．流網・特許出願公告昭和34年　第8382号．特許庁．
10）渡辺　　享：1959．沈子方に緩衝装置をつけた流網・特許出願公告昭和34年 第5719号．特許庁．
11）渡辺　　享：1959．流網・実用新案登録番号　第497532号．（実用新案出願公告昭和34年 第5764号）．特許庁．
12）鳥居敏雄，高橋暁正，土肥一郎：1954．推計学．財団法人東京大学出版会．
13）小松　勇作：1950．生物統計学．朝倉書店．

"イタニグサ" *Ahnfeltia plicata* より寒天の新製造法に関する研究 - I.※

小島良夫・福島保明・香野　実

Studies on the New Method of Preparation of Agar agar from *Ahnfeltia plicata*—— I.※

By

Yoshio KOJIMA, Yasuaki FUKUSHIMA and Minoru KŌNO

So-called Itani or Saghalien agar had previously been prepared from *Ahnfeltia plicata* with calcium hydroxide soln. in the extraction as long as for 20 hrs. and dehydration and decolorization of dark brownish crude agar gel by natural freezing method. It was only 10 % in value of yield and 350 g/cm² in jelly strength, respectively.

The authors have made a new attempt to prepare a purified agar agar which can be worked all the year round by the following process.

1. Softening and decolorization of *Ahnfeltia plicata* by the dilute alkaline treatment.
2. Extraction of agar agar in a little time from the alkaline treated *Ahnfeltia plicata* with dilute alkaline soln. by the autoclave.
3. Removals of alkaline and coloring matters from crude agar gel by running water and breaching agent.
4. Dehydration of the crude agar gel by the mechanical press method.

The yield of agar agar obtained by these processes showed 16.8 % to the refined materials and jelly strength of it 650 g/cm².

I　ま　え　が　き

紅藻類オキツノリ科に属する"**イタニグサ**"は黒褐色の絲状海藻で皮質は軟骨質を呈し，本邦附近では北海道，樺太及び沿海州に産する。1907年小笠原は樺太遠淵湖の"**イタニグサ**"より初めて寒天の製造を試みたが失敗に終った。その後杉浦[1]によって石灰添加による常圧抽出法が研究され，1916年頃より樺太寒天或は伊谷寒天として市販されるようになった。その製造法は石灰添加の20時間常圧煮熟により寒天質を抽出して黒褐色の心太とする。これを樺太では細状にして雪原に並べて凍結し春先まで放置すると雪解けと共に心

※ 水産講習所研究業績　第289号，1959年11月2日受理
Contribution from the Shimonoseki College of Fisheries, No. 289.
Received November 2, 1959.
日本水産学会1958年10月秋季大会（新潟）及び
1959年4月春季大会（東京）にて発表

太の解氷脱色が行われる。又長野県では寒冷により凍結した黒褐色の細状心太に散水を反覆繰返して脱色する。何れの方法も天日乾燥により細状寒天を製造した。近年北朝鮮では石灰添加の加圧抽出法によって得た黒褐色の心太を樽太法で寒天を製造しているようである。

これ等の方法で得た寒天は稍々黄色を呈し，その収率は10～11%に過ぎなかった。

伊谷寒天は他の寒天に比して，1）ゼリー強度が高いこと，2）溶解性が良いこと，3）ゼリーの離漿水が甚だ少量であること，等の特殊な性質を有しているので生菓子或はゼリー菓子製造に特に需要が多かった。戦後樺太の失地から伊谷寒天の製造が中止されたか最近沿海州より“**イタニグサ**”の輸入が行われるようになった。しかし，前述のように抽出に長時間を要すること，心太の脱色が容易でないこと，から従来の方法では工業生産に不適当であるとみなされていた。そこで著者等は従来の方法によらず化学的な処理と機械的方法によって品質均一な伊谷寒天の製造を試みたのである。

著者の一人（小島）は既に“**オゴノリ**”より寒天の製造法を報告し[2]，その苛性処理廃液が濃緑褐色を呈し“**オゴノリ**”が或る程度脱色されることを見出したので“**イタニグサ**”も同様な方法で処理すれば或る程度の原藻脱色が出来ると考えて，処理方法についても研究した。

次に寒天質の定性的抽出実験の結果，単なる水又は微酸性溶液の加熱では全く抽出されず，アルカリ性溶液の加熱により抽出されることが判明した。アルカリ添加剤として NaOH, KOH, Na_2S, Na_2CO_3, $Ca(OH)_2$ の順に抽出率が良好であることも明かとなった。しかし，アルカリ抽出では色素が溶出して寒天液が黒褐色となる欠点がある。

そこで著者等は“**イタニグサ**”より寒天の製造法として

1．苛性ソーダ溶液による直接常圧或は加圧抽出法
2．稀薄苛性ソーダ溶液による原藻の前処理法
3．苛性処理“**イタニグサ**”の稀薄苛性ソーダ溶液による加圧抽出法
4．心太の脱色法

等について種々研究した結果，稀薄苛性ソーダ溶液で原藻を処理した後，稀薄苛性ソーダ溶液で加圧抽出をした場合，従来の石灰法の10～11 %に比して16 %の高収率を得，又そのゼリー強度も650 g/cm² を示す伊谷寒天を得ることに成功したのである。

Ⅱ　原　　藻

“**イタニグサ**”は1957年沿海州産にて採取されたものを風乾して圧搾梱包し各々約50kgとして輸入された。原藻を水洗しつつ，充分柔捻し，附着黄泥を除去して風乾した。その草歩は平均79 %であった。この精原藻は水分約11%を有し以下の研究試料に供した。

Ⅲ　苛性ソーダ溶液による直接抽出法

1）常圧抽出について

精原藻64 g を種々濃度の NaOH 溶液1500 $m\ell$ と共に逆流冷却器を附して加熱煮熟し，藻体が軟化して繊維のみとなった時まで抽出を行った。濾布で吸引濾過し，残渣を圧搾して附着寒天液は濾液と合した。濾液を一定容器に注入して一夜放置すると黒褐色の心太が得られた。この際濾液に硫黄系還元漂白剤を添加して脱色を試みたが硫黄化合物が生成沈殿し不適当であった。又次亜塩素酸ソーダ，塩素水又は過酸化水素等の酸化漂白剤の添加は多少脱色効果がみられたが心太の強度低下著しく適当でなかった。そこで心太を細状に切断して流水中に浸漬すると最初は著しく清水交換が進み，脱色素及び脱アルカリが行われたが時間の経過と共に交換速度が緩慢となり18時間後では殆んど変化が見られなかった。しかし，この方法により黒褐色の心

Table 1. Results on the preparation of agar agar from *Ahnfeltia plicata* with NaOH soln. by the method of atomospheric extraction. (taken sample, 64g; volume of NaOH soln., 1500 ml; decolorization time of crude agar gel by running water, 18hrs.).

Exp. No.	Extraction		Breaching of dehydrated agar gel	Agar-agar		
	Concns. of NaOH soln. (%)	Time in hrs.		yield (%)	Jelly strength (g/cm^2)	Color
1	0.53	4.5	0.1 % $Ca(OCl)_2$	13.6	—	brown
2	0.53	5.5	0.2 % $Ca(OCl)_2$	14.1	630*	yellowish brown
3	0.40	5.5	0.1 % $Ca(OCl)_2$	12.5	—	brown
4	0.67	4.5	0.25% $Ca(OCl)_2$	14.4	510*	yellowish brown
5	0.80	3.5	0.2 % $Cu(OCl)_2$	15.8	380*	〃
6	1.06	3	〃	17.8	500*	〃
7	1.06	4	0.3 % NaOCl	17.4	590	yellow

* in soluble matter were appeared.

太はほぼ脱色されて稍々乳褐色を呈するに至った。この心太を −5 °C で12時間凍結した後，解氷，脱水及び乾燥すると稍褐色の寒天となった。これは外観乳褐色の心太を凍結すると周囲の水が氷となるに従って色素は次第に中心部に濃縮されるので解氷後の寒天ゲルは特に中心が褐色を呈することになる。次にこの脱水寒天ゲルを更に脱色する目的で次亜塩素酸石灰液で処理したが寒天に石灰が沈着して製品が白濁し，そのゼリーに不溶性物質が生成した。しかし次亜塩素酸ソーダ液で処理すると色調，光沢も良好な製品となり，寒

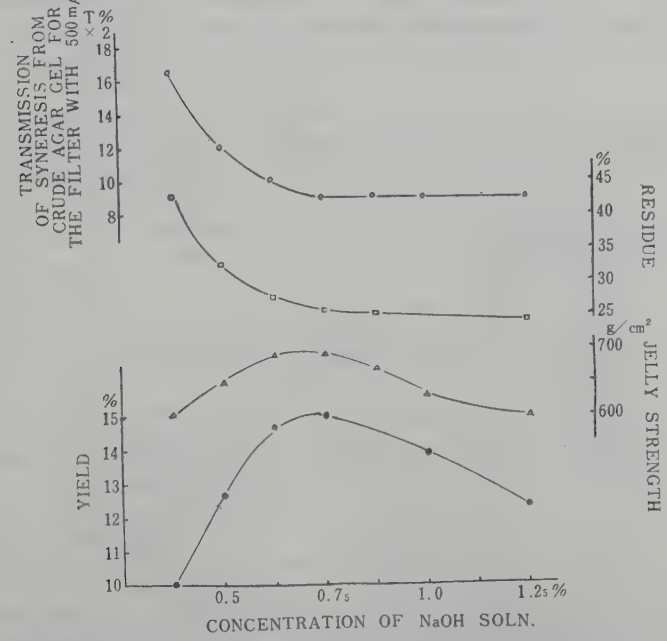


Fig. 1. Variations of color tone of crude agar gel, residue contents, yield and jelly strength of agar agar obtained from *Ahnfeltia plicata* with various concns. of NaOH soln. by the atomospheric extraction method. (taken sample, 30g; NaOH soln, 800ml; boiling time, 5 hrs.)

天ゼリーに不溶性物質の生成もなく良好であった。

種々濃度の苛性ソーダ溶液で常圧抽出を行った場合の結果は第1表に示すようである。

苛性ソーダの濃度の増加に従って寒天収率は増加するが着色度が著しく脱色が容易でなかった。一般に着色度の著しい寒天は収率が良好であるがゼリーは稍々黒褐色を呈し，漂白剤で脱色するとゼリー強度の低下が顕著に現われた。

次に精原藻 30 g を各濃度の苛性ソーダ溶液 800 $m\ell$ で常圧5時間煮熟し，前述と同様に行った。脱水寒天ゲルの脱色には0.3 % NaOCl 溶液を用いた。抽出条件による心太の着色度を比較するために細状心太からの離漿液の2倍稀釈液を 500 $m\mu$ フィルターに対する透過率で求めた。又抽出率を比較するために抽出後の圧搾残渣を数回水洗してアルカリ及び色素を除去し，脱水，乾燥して原藻に対する残渣の%を求めた。

これ等の結果は第1図に示すようである。

0.75 %の NaOH 溶液の場合15%の最も良好な寒天収率を得た。これ以上の濃度では加水分解のため低下値を示した。心太の着色度も 0.75 % 濃度までは増加するがそれ以上では変化しないようである。残渣率も 0.75 %濃度までは急激に低下するが，それ以上の濃度では僅かに減少する傾向を示した。これは苛性ソーダと加熱によって繊維が分解されていくためと考えられた。

2）加圧抽出について

"**イタニグサ**" のように皮質の硬い海藻から常圧で寒天質を抽出するにはアルカリの濃度を増加すれば容易である。しかし前述のように心太の着色度が著しいので脱色が容易でない。そこで著者等は抽出に際し加圧すれば低濃度のアルカリで短時間に良好な抽出率を得ることが出来ると考えた。

実験に使用した加圧抽出器は二重浴式で水蒸気温度 100°C において精原藻及び NaOH 溶液を入れた容器を収容し，再び 100 °C に達した時密閉して加熱した。熱源を調節して 120°C で所要時間を保つようにした。100°C より 120°C までの所要時間は20分，又抽出終了から濾過温度 95°C までの放冷時間は 40分であった。抽出後の操作は常圧抽出の場合と同様に行った。これ等の結果は第2表に示すようである。

Table 2. Results on the preparation of agar agar from *Ahnfeltia plicata* with NaOH soln. by the method of press extraction. (time of extraction, 3 hrs. ; decolorization time of crude agar gel by running water, 18 hrs.).

Exp. No.	Taken sample (g)	Extraction: Concns. of NaOH soln. (%)	Extraction: Volum of NaOH soln. (ml)	Extraction: temp. (°C)	Neutralization for filtrate	Breaching of dehydrated agar gel	Agar-agar: Yield (%)	Agar-agar: Jelly strength (g/cm²)	Agar-agar: Color
8	32	0.30	800	120	—	—	13.4	690	black
9	32	0.44	800	120	4 ml of 3.6%HCl	1ℓ of 0.25% NaOCl	15.6	520	yellow
10	32	0.50	800	115	—	—	17.2	850	black
11	32	0.50	800	120	—	1ℓ of 0.45% NaOCl, 30 min	16.6	620	yellow
12	32	0.50	800	120	4 ml of 3.6%HCl	1ℓ of 0.2% NaOCl	12.5	400	yellow
13	48	0.72	840	120	—	1ℓ of 0.24% NaOCl, 30 min	16.9	730	yellow
14	56	0.72	980	120	—	1ℓ of 0.3% NaOCl, 30 min	16.1	760	yellow

抽出後の濾液を塩酸で中和した No. 9 及び No. 12 の場合は寒天の収率及びゼリー強度が低下し有効でなかった。No. 10 のように心太を流水中 18 時間水洗したのみでは矢張り寒天は黒褐色を呈した。しかし寒天の収率は17.2 %，ゼリー強度は 850 g/cm² であった。No. 13 及び No. 14 のように精原藻に対して 17.5倍の液量の 0.72 % NaOH溶液で 120°C，4 時間抽出した場合，流水漂白，0.3 % NaOCl による脱水寒天ゲルの

漂白等を行ったものは収率16.1～16.9％，ゼリー強度730～760 g/cm² の稍々黄色の寒天を得た。

以上の結果から加圧抽出の方が常圧抽出よりも低いアルカリ濃度で短時間で高い収率の寒天を得ることが出来た。

Ⅳ　原藻の前処理法

前項に記したように"**イタニグサ**"をアルカリ性溶液で常圧或は加圧で煮熟すると寒天質が抽出されると同時に含有色素もアルカリに溶解してくる。従って寒天液が著しく黒褐色となる。そこで著者等は色素がアルカリに可溶性であることから"**イタニグサ**"を稀薄アルカリ溶液で寒天質を溶出させることなく，色素のみを溶出させるような適当な条件で処理すれば原藻を或る程度脱色出来，又アルカリによって皮質が軟化すれば以後の操作の寒天質の抽出も容易に出来るものと考えた。

1）実　験　の　部

精原藻を処理液に充分浸漬すると，その液量は原藻重量に対して平均29.7倍であった。そこで先づ精原藻30 g を1％ NaOH 溶液 800 ml に浸漬して処理温度90°C で4時間処理したところその処理廃液を放冷すると完全に凝固した。これは明かに寒天質が溶出されたことを示した。即ち処理濃度と温度の両因子によって寒天質が溶出されるものと考える。

故に処理の苛性ソーダ溶液の濃度をそれぞれ0.75，0.563，0.375，0.1875 ％とし処理温度を70°C，80°C，

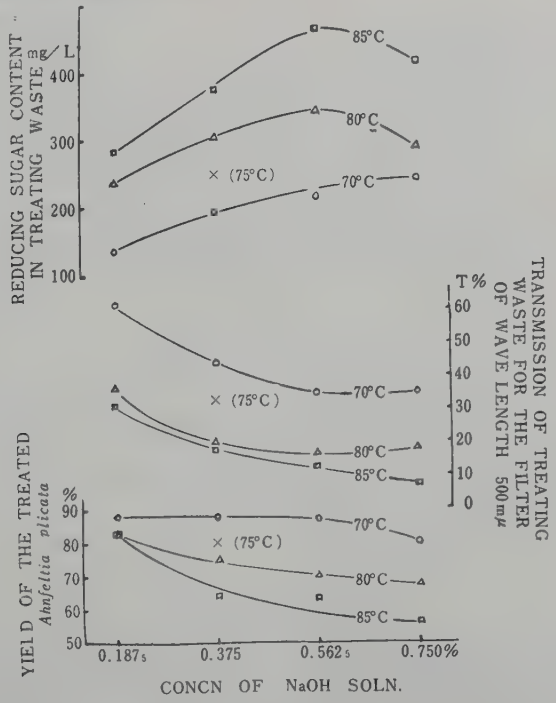


Fig. 2. Variations of color tone of treating waste and reducing sugar contents in it, and yield of *Ahnfeltia plicata* treated with alkaline soln. at various temps. for 4 hrs. (taken sample, 30g ; treating soln., 800ml.).

85°C として4時間処理した。処理後 "**イタニグサ**" を充分水洗して脱アルカリし，60°C で乾燥して収率を求めた。各処理廃液は，一夜放冷して gel 化状態を検し，更に硝子濾斗で濾過し，液中の還元糖量を Bertramd 氏法で定量した。同時に光電比色計により波長 500 mμ のフィルターに対する透過率を測定して着色度を比較した。これ等の結果は第2図に示すようである。

2）結果及び考察

処理において苛性ソーダの濃度及び温度の増加によって処理廃液の着色度，含有還元糖量等が増加するが**処理いたにぐさ**の収率は減少した。0.563 % の苛性ソーダ溶液以上で 80°C の処理温度以上では処理廃液が gel 化した。それ故 gel を除いた液中の還元糖量を求めたので過小価を示した。0.75 % の苛性ソーダ溶液では 70°C の処理温度でも廃液は gel 化しなかった。以上の結果から，この処理条件では寒天質の溶出は処理濃度よりも温度に影響されるものと考える。即ち処理温度 80°C 以上は適当でなく，75°C 以下で 0.375 % の濃度で4時間処理すれば寒天質の液出もなく，或る程度の脱色がみられた。

〔処理廃液の吸収曲線〕

"**イタニグサ**" 前処理液として 50, 65, 75 % メタノール溶液に苛性ソーダを添加溶解してアルカリ濃度を0.375 % とした。

精原藻 15 g に前記のアルカリ含有メタノール溶液 400 $m\ell$ を加えて逆流冷却器を附し，75 °C で4時間処理した。硝子濾斗にて濾過した濾液を光電光度計にて吸収曲線を求めた。その結果は第3図に示すようである。

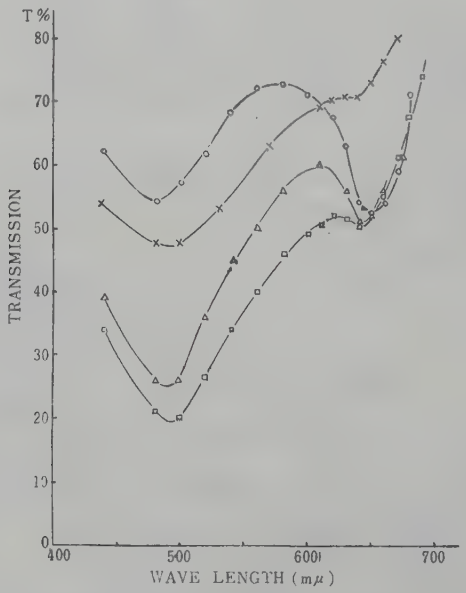


Fig. 3. Change in transmission of alkaline extracts obtained from 15 g of *Ahnfeltia plicata* with 400ml of 0.375 % NaOH soln. at 75°C for 4 hrs. —○—, containing 75 % methanol; —△—, contg. 65 % MeOH; —□—, contg. 50 % MeOH; —×—, without MeOH.

即ち "**イタニグサ**" より溶出した色素のアルカリーメタノール一水系では 480～490 mμ と 640 mμ にお

いて最大吸収部が見られた。これ等の結果から0.375% 苛性ソーダ水溶液のみで処理するよりも50% のメタノールを含有した溶液で処理した方が色素の溶出が良好であることが示された。

V　処理イタニグサより寒天の加圧抽出法

"**イタニグサ**" を前項の最適条件で6回前処理した結果は第3表に示すようである。

Table 3. Treatment of *Ahnfeltia plicata* with the dilute alkaline solution.

Refined raw material	Volume of 0.375% NaOH soln	Conditions of treatment	Weight of treated material	Yield (av. in six times)
(g)	(ml)		(g)	(%)
70	1870	75°C, 4hrs.	56.25	80.4

精原藻70 g を0.375%苛性ソーダ溶液 1870 $m\ell$ で 75° C において 4 時間処理した後，充分水洗して脱アルカリし，風乾して **処理イタニグサ**とした。その平均収率は 80.4 % であった。この **処理イタニグサ** から NaOH或はNa_2CO_3 の抽出剤で加圧法によって寒天質を抽出した。

1）苛性ソーダ溶液にて抽出した場合

a.　抽出濃度と時間との相対関係

加圧抽出法により寒天を製造するとき、その収率及びゼリー強度の良否を左右する因子は抽出温度，濃度，及び時間等である。著者等は工業的生産において比較的容易に扱い得る温度を 120° C までと考えて，先ず抽出温度を 120° C とした。そこで温度を一定とした場合濃度と時間とどちらかが大きな抽出因子となるかを検討した。即ち苛性ソーダの濃度と抽出時間との相乗積を一定にして抽出を行った。

処理イタニグサ 40 g にそれぞれ濃度0.72～0.25 %の苛性ソーダ溶液 1 ℓ を加えて 120° C で 2～6 時間抽出を行った。抽出後 2 枚の木綿布で濾過した。残渣は水洗後乾燥して精原藻に対する%で，又心太よりの離漿液は 2 倍に稀釈して透過率を測定した。心太は細状にして 18時間流水交換して漂白し，－5 ° C で 12時間凍結した。解氷，脱水後，更に 0.3 % NaOCl 溶液で20分間漂白し，水洗後，乾燥して伊谷寒天とした。これ等の結果は第4表に示すようである。

Table 4. Relation between the concentration of NaOH soln. and time in the extraction of agar agar from *Ahnfeltia plicata* at 120°C. (treated *Ahnfeltia plicata*, 40 g; volume of NaOH soln., 1000ml.)

Exp. No.	Extraction		Crude agar gel		Residue	Agar-agar	
	Concns. of NaOH soln. (%)	Time (hrs.)	Tranomission(500mμ) of syneresis(×2) (%)	Jelly strength (g/cm²)	(%)	Yield for the refined material (%)	Jelly strength (g/cm²)
15	0.72	2	8.0	445	23.0	15.8	645
16	0.50	3	8.0	455	23.8	16.8	670
17	0.38	4	10.0	415	25.7	15.2	455
18	0.30	5	11.5	380	28.0	15.0	540
19	0.25	6	11.5	370	30.8	14.6	440

抽出濃度と時間の相乗積を一定にした条件であるが表に見るように濃度の高い程，心太の着色度及びゼリー強度並に寒天の収率が高い値を示した。即ち抽出時間よりも濃度の影響の方が大きいことを示した。

No. 15の0.72%の濃度で2時間の抽出では抽出率は良好であるが，心太のゼリー強度及び収率が低下した。これは苛性ソーダの過剰により寒天質の一部が分解したためと考えられる。No. 16 の 0.5%濃度で 3 時間抽出の場合が最も良好な結果を示した。

b.　抽出温度及び濃度を一定とした場合

前述の最適抽出濃度0.5%苛性ソーダ溶液 1 ℓ で温度 120° C にて種々の抽出時間で**処理イタニグサ**40 g から寒天質を抽出した結果は第 5 表に示すようである。抽出時間の増加に従って抽出率及び心太の着色度は増

Table 5. Yield and jelly strength of agar agar obtained form *Ahnfeltia plicata* with 1000 ml of 0.5 % NaOH soln. at 120°C for various hrs. (treated *Ahnfeltia plicata*, 40 g.)

Exp. No.	Hrs. of extractiosn	Crude agar gel		Residue (%)	Agar-agar	
		Transmission(500mμ) of syneresis(×2) (%)	Jelly strength (g/cm²)		Yield for the refined material (%)	Jelly strength (g/cm²)
20	2	10.5	435	25.1	15.4	520
21	3	8.0	455	23.8	16.4	670
22	4	8.0	465	23.4	15.8	530
23	5	7.5	420	22.6	16.2	665
24	6	5.5	530	22.2	16.6	590

加するが 3 時間以後では寒天の収率及びゼリー強度の変化は余りみられなかった。

c.　抽出温度及び時間を一定とした場合

前述と同様に抽出温度を 120° C，抽出時間を 3 時間として苛性ソーダ溶液の濃度を種々変えて寒天質を抽出した結果は第 6 表に示すようである。No. 25のように抽出濃度の低いときは心太の着色が著しくなく脱色も容易であったが寒天の収率が良好でなかった。濃度の増加に従って心太のゼリー強度及び着色度並に寒

Table 6. Yield and jelly strength of agar agar obtained from *Ahnfeltia plicata with* 1000 ml of various concns. of NaOH soln. at 120°C for 3 hrs. (treated sample, 40 g.)

Exp. No.	Concns. of NaOH soln. (%)	Crude agar gel		Residue (%)	Agar-agar	
		Transmission(500mμ) of syneresis(×2) (%)	Jelly strength (g/cm²)		Yield for the refined material (%)	Jelly strength (g/cm²)
25	0.2	20.0	330	43.2	13.2	640
26	0.3	13.5	400	29.2	14.8	610
27	0.4	8.0	435	25.2	15.6	610
28	0.5	7.5	490	23.8	17.0	620
29	0.6	7.0	475	20.8	15.8	620
30	0.7	6.0	480	21.2	16.4	600

天の収率等増加し，No. 28の 0.5%濃度では最も良好な結果を示した。これ以上の濃度では収率およびゼリー強度の低下を示した。

d.　抽出温度132° Cにて行つた場合

処理イタニグサ40 g を種々濃度の苛性ソーダ溶液 1 ℓ にて温度132° C で種々の抽出時間で寒天質を抽出した場合の結果は第 7 表に示すようである。寒天収率の良好な点の条件を求めると前述の抽出温度120° C の場合に比して逆に低い抽出濃度が示された。即ちNo, 33のように良好な寒天収率16.6%を得る条件は抽出濃度

0.3%抽出時間3時間であった。又No. 37及び39のように抽出濃度が増加すると心太の着色度が増して脱色困難となり製品が褐色を帯びるようになる。このような製品は一般にゼリー強度は高い値を示す。しかし濃度過剰のため寒天収率はむしろ低下を示した。

Table 7. Yield and jelly strength of agar agar obtained from *Ahnfeltia plicata* with 1000 ml of various concns. of NaOH soln. at 132°C for various hours. (treated sample, 40g.)

Exp. No.	Extraction		Crude agar gel		Residue	Agar-agar		
	Concns. of NaOH soln. (%)	time in hrs.	Transmisson (500mμ) of syneresis(×2) (%)	Jelly strength (g/cm²)	(%)	Yield for the refined material (%)	Jelly strength (g/cm²)	Color (*)
31	0.2	4	10.5	460	30.0	14.4	570	+
32	0.3	2	8.0	480	25.9	15.8	570	++
33	0.3	3	5.8	470	25.9	16.6	600	++
34	0.3	4	5.0	455	24.7	16.2	545	++
35	0.4	1	—	—	25.7	16.2	520	+
36	0.4	2	—	515	23.4	16.3	600	++
37	0.4	3	3.8	485	22.3	16.0	660	+++
38	0.5	1	8.0	500	26.1	15.2	640	++
39	0.5	2	5.0	535	21.6	15.7	650	+++

* +…white, ++…a little yellow, +++…brownish yellow.

2) 炭酸ソーダ溶液にて抽出した場合

前項までは強塩基の苛性ソーダによって"**イタニグサ**"より寒天質を抽出したため心太が著しく着色し脱色が容易でなかった。この欠点を少くするため炭酸ソーダによる抽出を試みた。その結果は第8表に示すようである。

Table 8. Yield and jelly strength of agar agar obtained from *Ahnfeltia plicata* with 1000 ml of various concns. of Na_2CO_3 soln. at 120°C or 132°C for various hours. (treated sample, 40g.)

Exp. No.	Extraction			Crude agar gel		Residue	Agar-agar	
	Concns. of Na_2CO_3 soln. (%)	Temps. (°C)	hrs.	Transmission (500mμ) of syneresis(×2) (%)	Jelly strength (g/cm²)	(%)	Yield for the refined material (%)	Jelly strength (g/cm²)
40	0.65	132	1	10.0	315	38.4	12.4	560
41	*0.4	132	3	7.0	270	36.9	11.2	500
42	0.4	132	4	6.5	360	30.4	13.7	570
43	0.8	120	3	7.0	348	32.4	13.7	665
44	1.0	120	3	6.0	395	32.0	14.5	720
45	1.2	120	3	4.5	435	30.6	14.1	710

* added 1g of $Na_2C_2O_4$

No. 41は抽出の際溶出する不純物としての石灰塩を除去する目的で$Na_2C_2O_4$を併用したが過剰が完全でなく製品のゼリーに不溶性CaC_2O_4が生成沈殿し効果はなかった。心太の着色度はNaOH使用の場合より著しくなく脱色も容易で色調良好な製品が得られた。しかし寒天の収率はNaOH使用の場合に比して劣る結果を示した。

Ⅵ 総　　括

著者等は石灰煮熟法によらず“**イタニグサ**”より寒天の新製造法として苛性ソーダ溶液による抽出法を提唱した。各項における最適条件の結果を第9表にそれぞれ示した。

Table 9. Agar agar obtained from *Ahnfeltia plicata* at the optimum condition for extraction.

Extraction			Crude agar gel			Agar-agar		
Kinds of reagents	Temps. (°C)	Hrs.	Transmission (500mμ) of syneresis (%)	Jelly strength (g/cm²)	Residue (%)	Yield for the refined material (%)	Jelly strength (g/cm²)	
0.75% NaOH	100	5	9.0(×2)	—	26.8	*15.0	540	①
0.5 % 〃	100	7	—	—	—	15.0	530	①
0.72% 〃	120	3	—	—	—	*16.5	740	
0.5 % 〃	120	3	8.0(×2)	470	23.8	16.8	650	
0.3 % 〃	132	3	5.8(×2)	470	25.9	16.6	600	②
0.2 % $Ca(OH)_2$	120	6	39.0(×1)	105	51.8	7.0	—	②
0.2 % $Ca(OH)_2$	132	4	61.5(×2)	135	49.0	10.0	600	
1.0 % Na_2CO_3	120	3	6.0(×2)	395	32.0	14.5	720	

＊—without alkaline treated sample
①—atomospheric extraction
②—pressure extraction

この表より本研究の総括を以下記述する。

1）“**イタニグサ**”を直接苛性ソーダ溶液にて常圧抽出する方法は5時間の抽出時間を要し収率15%でゼリー強度も 540 g/cm² で良好でなかった。

2）苛性ソーダ溶液による直接加圧抽出法は収率及びゼリー強度も良好であったが心太の脱色困難のため寒天の着色は免かれなかった。

3）“**イタニグサ**”を稀薄苛性ソーダ溶液で75°C 以下にて4時間処理する方法によって原藻の色素を或る程度除去することが出来，又同時に繊維が軟化して寒天質の抽出が容易になった。

4）**処理イタニグサ**を苛性ソーダ，炭酸ソーダ及び石灰溶液等で加圧抽出を行った結果，石灰液よる抽出が最も劣り，寒天収率10 %に止まった。
炭酸ソーダ溶液による抽出も14.5%に過ぎなかった。結局**処理イタニグサ**を0.5%苛性ソーダ溶液にて120°C 3時間抽出する方法によって寒天の収率16.8 %，ゼリー強度 650 g/cm² を示す好成績を得た。

終りに臨み本研究の遂行に当り援助を与えられた東海化成株式会社（神奈川県平塚市）並に化研工業株式会社（長野県茅野市）に深謝する次第です。

文　　献

1. 杉浦六弥：1915. 日本特許28,066号
2. 小島良夫・舟木好右衛門：1951. “おごのり”より寒天の製造に関する研究，Ⅰ. Ⅱ. Ⅲ. Ⅳ. 日本水産学会誌，**16**(9)，401—422.

ウニ塩辛に関する研究—I.

ウニ塩辛の貯蔵中における成分変化について※

畑　幸彦・河内正通

Studies on "Uni-Shiokara" —— I.

Changes in Chemical Composition of "Uni-Shiokara" during the Storage※

By

Yoshihiko HATA and Masayuki KŌCHI

In the manufacture of "Fish-Shiokara" muscles and guts of fish are mixed with salt, and they are usually ripened in a vat for several weeks. Some enzymatic autolysis and microbial decomposition of raw materials probably take place in the ripening process. It is generally supported that this treatment results in desirable changes in taste and flavor of the "Shiokara". However, "Uni-Shiokara" which is prepared with gonad of sea urchin, salt and a small amount of alcohol is expected to differ in various respects from "Fish-Shiokara".

In the present paper the authors attemped to elucidate the changes in chemical composition and microbial population of "Uni-Shiokara" during the storage.

The results obtained are shown in Tables 1—8 and Figs. 1—5, and may be summarized as follows:

1) Chemical composition of gonad of sea urchin which were used as the raw materials of "Uni-Siokara" considerably varied with the locality and the species.

2) Changes in chemical composition of "Uni-Shiokara" during the storage were, in spite of the low concentration of salt in it, remarkably retarded as compared with those during the ripening process of "Fish-Shiokara" containing salt in the higher concentration. This may be due to the inhibitory effect of alcohol on the autolysis and microbial activity in "Uni-Shiokara".

一般に，塩辛類は通常の塩蔵品と異なり，貯蔵中に呈味成分が増加し，これが食塩と融和して特有の香味を生ずる，いわゆる熟成を起させることが肝要である。一般塩辛類の熟成過程中における成分変化およびこれに及ぼす用塩量の影響などについては，松井・深山[1]・島田・馬場[2]，清水[3]，長尾・木村[4]，長尾[5]お

※ 水産講習所研究業績　第290号，1959年11月2日受理
Contribution from the Shimonoseki College of Fisheries, No. 290.
Received November 2, 1959.

よび長崎・山本[6]らの報告があり，殊に長尾らはイカ塩辛の熟成について細菌学的立場から詳細に研究した。

しかるに，ウニ塩辛は他の一般塩辛類とは種々の点で著しい相違があるにもかかわらず，異常醗酵の原因およびその防止法について二・三の報告[7][8]があるに過ぎず，貯蔵中における成分変化などの基礎的研究は殆んどなされていない。

よって著者らは，微生物学的ならびに化学的見地からウニ塩辛の製造，貯蔵中における諸変化を追究して，いくつかの知見を得たので報告する。

なお，今回研究の対象としたのは，いわゆる泥ウニ（粒ウニ）であって，なかでも下関地方で製造されるアルコールを加えた製品に限定した。

Ⅰ．ウニ塩辛の製造法について

下関地方の泥ウニの製造には，浜詰法といわれる従来の小規模方式と樽詰法ともいうべき量産方式とがある。前者は山口県北浦地方産の新鮮原料に，適当量の食塩，アルコールを加え直接壜詰めする方法で，原料ウニの漁期である夏季に限られている。後者は北浦地方産および他の地方産の，あらかじめ現地で食塩を施し樽詰めした原料を冷蔵しておき，必要に応じてアルコール，食塩および調味料などを加えて大型の樽または瀬戸びきタンクに入れ，蓋をして数週間室温に放置し*，その後壜詰めするもので，周年にわたって操業できる。

一般に原料は，バフンウニ(*Strongylocentrotus pulcherrimus*)を最上としてムラサキウニ(*Heliocidaris crassispina*)およびエゾバフンウニ（*Strongylocentrotus intermedius*）などの生殖巣を適当に混用するが，卵巣と精巣との混在比は不明である。

Ⅱ．原料生殖巣の成分ならびに微生物について

ウニの種類および産地の別，あるいは新鮮原料と冷蔵原料との相違などによって原料生殖巣の成分にはかなり差異のあることが予想されるが，これらは当然製品の品質に影響を与えるものと思われる。よって先ずこの点を明らかにするため，現在下関地方で普通に用いられている原料について，化学成分ならびに存在する微生物を調べた。

化学成分の定量法は次の通りである。試料を乳鉢でよく擂潰し，一部をとって全窒素を定量し，他の一部に5倍量の蒸溜水を加えてpHをガラス電極で測定した。

また残部を精秤し，蒸溜水を加えて抽出・遠心分離を繰返し，その抽出液の一部について水溶性窒素および還元糖を定量した。

更に，上記抽出液の一部に三塩化酢酸を加え除蛋白・遠心分離して後，非蛋白態窒素，アミノ態窒素および揮発性塩基窒素の定量に供した。

各態窒素の定量は常法により，還元糖の定量はLEHMANN—MAQUENNE-SCHOORL法によった。なお，各態窒素量は全窒素に対する百分率によって示した。

微生物の計数には，滅菌乳鉢で擂潰した試料を滅菌生理的食塩水（培地AおよびNに対して）または滅菌10%食塩水（培地BおよびPに対して）で10倍宛に稀釈し，第2表に掲げる各種培地を用い30°Cで混和平板培養して，1週間後に全集落を計数した。

それらの結果は第1および2表に示す通りである。

すなわち，これら原料生殖巣の特徴は，北浦産および牛深産のものが脂肪に富むのに対して北海道産のものは極めて少なく，また北浦産のものは北海道産，牛深産のものに比して灰分（食塩を除く）が甚だ少なかったことである。下関地方では，これら三種類の原料のなかでは北浦産，牛深産，北海道産の順に品質が劣るとされているが，恐らくその理由の一部はこれら成分の差異と関係があるものと考えられる*。

* 業者はこれを熟成と称し，強いアルコール臭が消失するのを限度としている。

Table 1. Chemical composition of gonad of sea urchin used as raw materials of "Uni-Shiokara."

Sea urchin		Moisture	Crude fat	Ash*	NaCl	Reducing sugar	pH	Total N	Comparative amounts in various fractions of nitrogen (% of Total N)			
Locality	Species	(%)	(%)	(%)	(%)	(%)		(%)	Water soluble N	Non-protein N	Amino N	Volatile basic N
Kitaura (Yamaguchi Pref.)	*Stronoylocentrotus pulcherrimus* (70 %); *Heliocidaris crassispina* (30 %)	57.8	10.9	1.8	—	0.75	6.46	2.9	81.8	79.7	4.65	0.49
Ushibuka** (Kumamoto Pref.)	*Heliocidaris crassispina*	56.1	14.3	4.4	13.1	1.38	5.94	2.2	68.9	68.9	24.75	4.94
Rijiri** (Hokkaido)	*Strngylocentrotus intermedius*	50.7	3.4	4.2	11.2	0.85	5.56	3.6	76.6	70.3	21.74	1.64

* excepting NaCl

** These samples had been refrigerated before the analysis for about 2 months after catch.

Table 2. Number of micro-organisms contained in gonad of sea urchin used as raw materials of "Uni-Shiokara." Samples tested were the same as those shown in Table 1. (Viable cells in 1 g of sample.)

Locality of sea urchin \ Medium employed for plate counts*	A	B	N	P
Kitaura **	8.0×10^5	6.0×10^5	8.0×10^4	—
Ushibuka ***	2.5×10^6	3.8×10^6	2.1×10^6	3.3×10^6
Rijiri ***	5.0×10^5	1.8×10^5	1.1×10^6	1.2×10^6

* Medium A : Nutrient broth agar.
// B : Nutrient broth agar added with 10 % NaCl.
// N : Potato glucose agar.
// P : Potato glucose agar added with 10 % NaCl.

** Only bacteria were found on every media.

*** Not only bacteria but also yeasts were found on media N and P.

また，生深産，北海道産の原料は北浦産に比してアミノ態窒素および揮発性塩基窒素の含量が極めて大きく，PH 価が甚だ低かったが，これは恐らく冷蔵中に分解を受けて変化した結果であろう。

微生物については，通常の細菌はどの原料にも殆んど同様に多数存在したが，酵母は北浦産新鮮原料にはいずれの培地でも全く見出されなかったのに対して，生深産および北海道産の冷蔵原料には培地NおよびP上に多数見出された。これは，原料の処理および貯蔵中に増加したものではなかろうか。

つぎに，生深産および北海道産原料を，そのまま更に約5カ月間（通算約7カ月間）引き続き冷蔵した場合の，成分および微生物数は第3および4表に示す通りである。

Table 3. Chemical properties of gonad of sea urchin refrigerated for about 7 months after the catch. Samples stored were the same as those shown in Table 1.

Locality of sea urchin	Content of reducing sugar (%)	pH	Content of total N (%)	Comparative amounts in various fractions of nitrogen (% of total N)			
				Water soluble N	Non-protein N	Amino N	Volatile basic N
Ushibuka	2.32	5.73	2.2	85.6	70.8	24.5	3.3
Rijiri	1.00	5.79	3.7	78.6	67.6	20.7	1.7

Table 4. Number of micro-organisms contained in gonad of sea urchin refrigerated for about 7 months after catch. Samples stored were the same as those shown in Table 2. (Viable cells in 1g of sample.)

Locality of sea urchin \ Medium employed for plate counts	A	B	N	P
Ushibuka	4.2×10^4	1.3×10^3	4.0×10^2	4.0×10^2
Rijiri	4.0×10^2	4.0×10^2	4.0×10^3	2.0×10^2

すなわち，これを第1および2表と比較すると，化学成分については，この5カ月間に北海道産には殆んど大きな変化が認められなかったのに対して，生深産のものには還元糖および水溶性窒素の著しい増加がみられた。この相違の理由は明らかでないが，水分，食塩含量および微生物にはそれぞれ大差がないから，原料自体の性質によるものかも知れない。

一方，生菌数については，北海道産，生深産とも明らかな減少が認められた。これは，この環境下において細菌が発育を抑制され漸次死滅することを示すものであろう。

Ⅲ．市販壜詰製品の成分ならびに微生物について

以上のように，原料生殖巣の相違によって成分にかなり差異のあることが明らかとなったが，これが製品の品質にどのような影響を及ぼすであろうか。また，長期間貯蔵した製品にはどのような成分変化がみられるであろうか。これらの点を明らかにするため，第5表に掲げる種種の市販製品について化学成分ならびに

* 一般にウニ生殖巣の化学的組成は，その成熟にともなって変化するものと予想され，またその成熟度は種類および産地の別によって時期的に差異があるものと考えられる。従って，以上の一試料のみについての結果から全般を推断することは，理論的には妥当ではない。しかしながら実際上ウニの採捕は，業者の経験によって操業上の好条件(たとえば採捕の難易さ，歩留，取引上の品質など)の時期に行われ概して短かい一定の期間に限られているのが実状である。而して本研究に用いた試料は，その盛漁期中のものであるから，少なくとも製造原料としてはそれぞれの代表的なものとみなし得る。この意味から，以上の分析の結果はそれぞれの原料の特質を示すものといえよう。

微生物数を調べた。試験の方法はIIに述べたと同様である。その結果を第5および6表に示す。

Table 5. Chemical properties of "Uni-Shiokara" on the market.

Mode of manufacture	Sea urchin: Locality	Sea urchin: Species	Time elapsed after manufacture	Moisture (%)	pH	Total N (%)	Comparative amounts in various fractions of nitrogen (% of total N): Water soluble N	Non-protein N	Amino N	Volatile basic N
浜詰 "Hamazume"	Kitaura	*Strongylocentrotus pulcherrimus*(70%); *Heliocidaris crassispina* (30%)	0	39.2	6.50	2.4	27.9	18.3	11.4	0.6
			1 year	36.3	6.18	2.4	46.6	41.2	14.8	1.0
量産 Mass production	Rijiri ; Ushibuka	*Strongylocentrotus intermedius*(40%); *Heliocidaris crassispina*(60%)	0	43.2	6.01	2.1	37.8	26.3	16.9	1.0
			3 months	45.0	6.21	2.2	39.0	26.2	15.4	1.4

Table 6. Number of microorganisms contained in "Uni-Shiokara" on the market. Samples tested were the same as those shown in Table 5. (Viable cells in 1g of sample.)

Mode of manufacture	Time elapsed after manufacture	Medium employed for plate counts: A	B	N	P
浜詰 "Hamazume"	0	1.0×10^5	8.6×10^2	4.6×10^3	1.4×10^2
	1 year	7.1×10^4	5.0×10^3	1.1×10^2	2.5×10^3
量産 Mass production	0	3.8×10^5	6.0×10^3	8.2×10^3	4.9×10^3
	3 months	5.7×10^5	1.0×10^3	4.0×10^4	1.0×10^2

すなわち，製造直後における成分を比較すると，量産製品は浜詰製品に比して水溶性，非蛋白態，アミノ態ならびに揮発性塩基窒素など低級窒素化合物が明らかに多かった。また約1カ年間室温で貯蔵された浜詰製品では，製造直後のものに比してこれらの値は著しく大きく量産製品の製造直後における値に匹敵するか，またはそれを上廻る値を示したが，一方夏季約3カ月間室温で貯蔵された量産製品には，壜詰め直後のものに比して殆んどみるべき差異がなかった。

これらのことは，新鮮原料を用いる浜詰製品は製造後漸次分解が進むのに対して，量産製品では製造前すでに原料の分解が進んでいるため，壜詰め後の変化は微弱であることを意味するものではなかろうか。

製品中の生菌数については，両製品ともほぼ同様であり且つ3カ月または1カ年貯蔵中に顕著な変動は起らないもののようである。

IV. 浜詰製品の貯蔵中における熟成について

以上の実験の結果，ウニ塩辛は長期間貯蔵中に蛋白態窒素が減少してアミノ態など低級窒素化合物がかなり増加し，また終始相当数の微生物が生存していることが明らかとなった。そこで，このような成分変化が一般塩辛類における熟成過程に比して如何なる特徴をもっているか，更にこの変化には自家消化酵素と微生物とのいずれが主として関与しているかなどの点を明らかにするため，北浦産新鮮原料を用い第7表に掲げる種種の処理を施した。

Table 7. The preparation of "Uni-Shiokara." The gonad of sea urchin which consisted of Strongylocentrotus pulcherrimus (70%) and Heliocidaris crassispina (30%) freshly caught at Kitaura were used as raw materials.

Sample number	Treatment
1	To 100g of gonad of sea urchin, 10g of baked salt and 14cc of absolute alcohol were added.
2	10g of toluene and 1g of chloroform were added to 100g of gonad of sea urchin treated in the same manner with sample 1.
3	After steaming at 98°C for 20 minutes, gonad of sea urchin were re-soaked in sea water. And then they were treated in the same manner with sample 1.
4	10g of toluene and 1g of chloroform were added to 100g of the untreated gonad of sea urchin.

これらを室温に放置して（7月15日開始），経時的に各種成分ならびに微生物の消長を調べた。その結果を第1－5図ならびに第8表に示す。

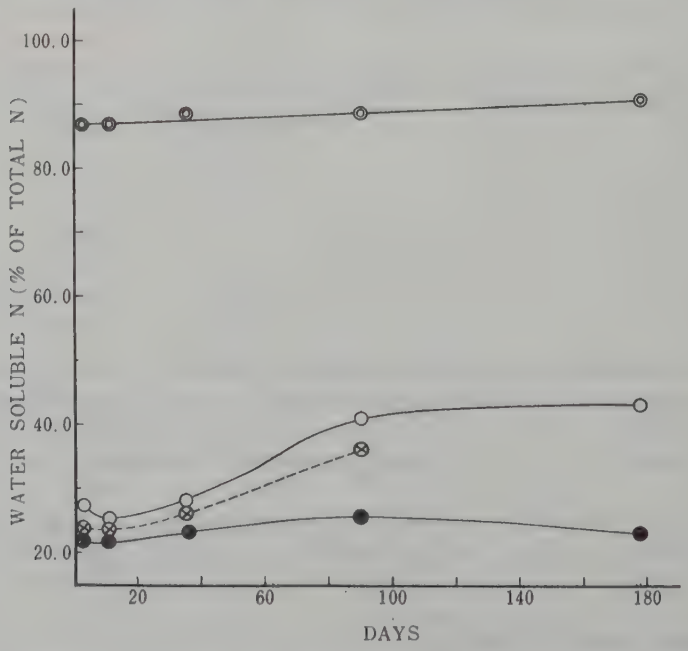


Fig. 1. Change of the amount of water soluble nitrogen in "Uni-Shiokara" during storage at room temperature. Samples tested were those shown in Table 7. —○—, Sample 1; ···⊗···, Sample 2; —●—, Sample 3; —◎—, Sample 4.

すなわちSample 4は他のものに比して成分変化が急激であって，水溶性，非蛋白態，アミノ態ならびに揮発性塩基窒素の増加および pH 価の降下が極めて著しかった。この Sample には，微生物の生育を阻止

し自家消化酵素作用のみを盛んに行わせる目的で，食塩，アルコールを加えずトルエン・クロロフォルム混液を添加したが，第8表にみられるように却って他のSample に比して生菌数が多く，且つ揮発性塩基窒素の生成量が甚だ大きかったことから，静菌作用は無効であったことが明らかである。従って，Sample 4 における上述の極めて急激な成分変化は，自家消化作用ならびに腐敗作用の両者による結果と解釈される。

これに対して，蒸煮によって自家消化酵素を破壊した Sample 3 （死滅した微生物を補うため，放冷後海水中に短時間再浸漬した）においては，これらの変化が極めて緩慢であった。また，Sample 1 および2は Sample 3 におけるよりもかなり大き い変化を示したが，Sample 4 と比較すれば甚だ微弱であった。而してこれらの成分変化は，Sample 4 を除くいずれの試料でも，既報の一般塩辛類の熟成中における変化に比すれば極めて緩慢であった。

生菌数は，初期においては Sample 1 および2に比して Sample 3 および4が著しく多かったが，その後 Sample 3 は速やかに，Sample 4 はこれよりおくれて減少して他の二者とほぼ同様の水準となった。またいずれの試料でも，生菌数は調製後ほとんど増加せず漸次減少する傾向を示した。この点は，イカ塩辛[5]において調製後約1カ月を最高としてかなり盛んな増殖がみられたということと甚だ異なるところである。

以上の試料に用いた食塩およびアルコールの濃度は下関地方で実用されている濃度の標準と思われるものであるが，これらの濃度においては上述のように成分変化は至って緩慢であり，また微生物の生育は十分抑制されていることが明らかとなった。而して上の結果において，蒸煮によって自家消化酵素を破壊したものでは微生物が比較的多かったにもかかわらず成分変化が特に僅少であり，また揮発性塩基窒素の増加が

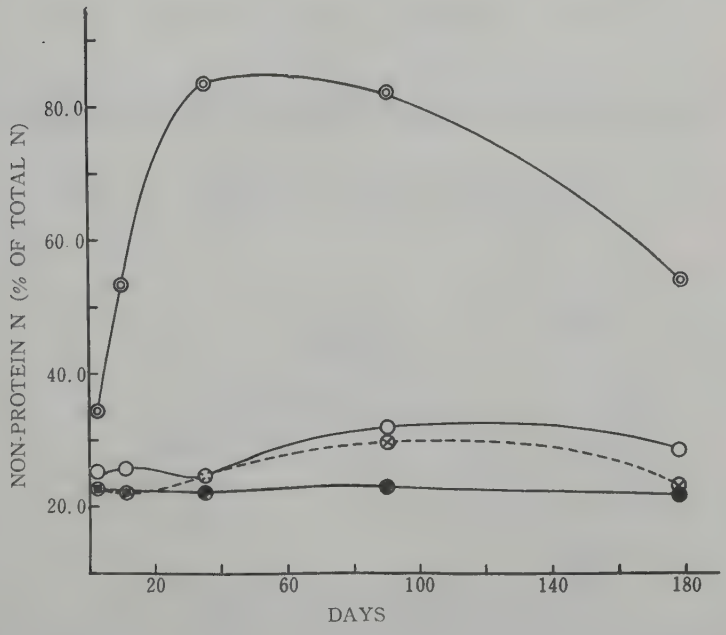


Fig. 2. Change of the amount of non-protein nitrogen in "Uni-Shiokara" during storage at room temperature. Samples tested and their marks were the same as those employed in Fig. 1.

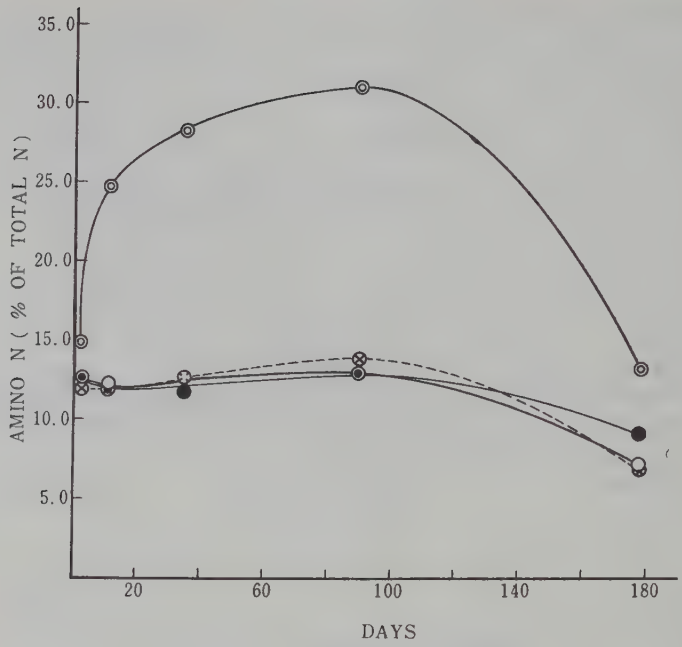


Fig. 3. Change of the amount of amino nitrogen in "Uni-Shiokara" during storage at room temperature. Samples tested and their marks were the same as those employed in Fig. 1.

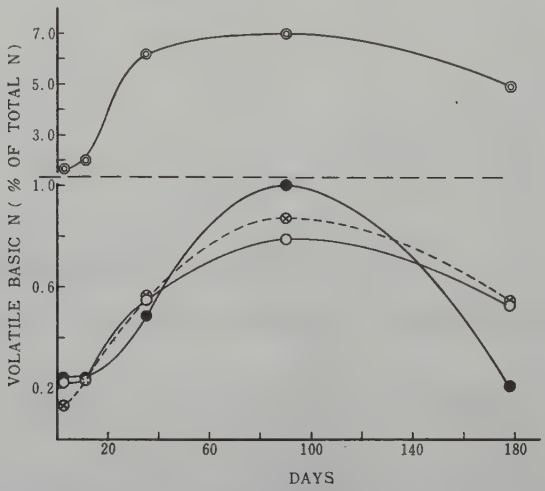


Fig. 4. Change of the amount of volatile basic nitrogen in "Uni-Shiokara" during storage at room temperature. Samples tested and the ir marks were the same as those employed in Fig. 1.

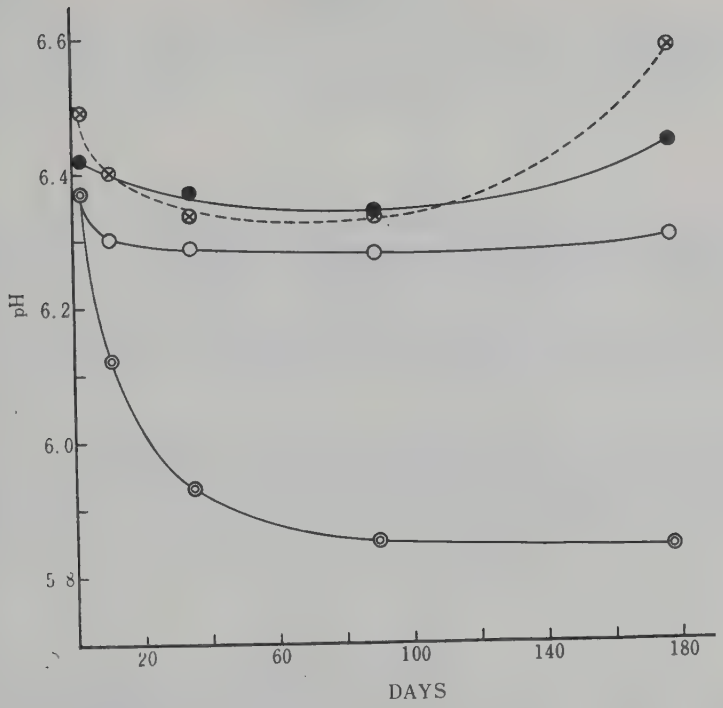


Fig. 5. Change of pH value in "Uni-Shiokara" during storage at room temperature. Samples tested and their marks were the same as those employed in Fig. 1.

Table 8. Number of micro-organisms contained in "Uni-Shiokara" during the storage at room temperature. Samples tested were those shown in Table 7. (Viable cells in 1g of sample.)

Sample number	Medium employed for plate counts	Time after preparation of samples							
		4 hrs	1	3	6	11	35	99	178 days
1	A	1.7×10^3	6.0×10^3	8.0×10^2	—	1.0×10^3	1.0×10^3	1.6×10^2	1.4×10^2
	B	7.2×10^2	2.4×10^3	8.0×10^2	1.6×10^3	3.6×10^2	4.0×10^2	6.0×10	2.0×10
	P	—	—	—	—	—	1.4×10^3	8.0×10	*
2	A	8.0×10^2	5.0×10^3	8.0×10^2	6.0×10^2	1.4×10^3	2.0×10^2	1.0×10^2	3.0×10^2
	B	6.0×10^2	3.0×10^2	6.0×10^2	5.7×10^2	2.0×10^2	2.0×10^2	1.2×10^2	*
	P	—	—	—	—	—	1.8×10^2	4.0×10	*
3	A	1.0×10^5	2.2×10^5	3.0×10^2	1.0×10^3	2.0×10^3	1.0×10^4	6.0×10	3.4×10^2
	B	3.6×10^3	4.0×10^2	6.2×10^2	5.8×10^2	6.0×10^3	*	2.0×10	6.0×10
	P	—	—	—	—	—	2.4×10^2	6.0×10	6.0×10
4	A	3.4×10^5	2.0×10^5	2.5×10^3	5.2×10^3	1.5×10^5	3.6×10^3	6.0×10	4.0×10^2
	B	2.2×10^5	1.4×10^5	3.0×10^4	1.4×10^3	2.0×10^3	2.0×10^2	6.0×10	*
	P	—	—	—	—	—	3.6×10^2	2.0×10	*

N. B. *…less than 10 cells.

Sample 4を除いては甚だ小さかったことから，これらの成分変化には恐らく自家消化酵素の方が微生物よりもより大きく関与しているものと考えられる。

なお，上の諸実験において分離された微生物の種類，性質などについては，後報において詳述する予定である。

総　括

ウニ塩辛は，地方によって原料および製造法が多少異なるので，その性状ならびに貯蔵中における変化にはかなりの相違があるものと思われるが，本研究の対象とした下関地方におけるウニ塩辛では，貯蔵中に成分，殊に含窒素化合物の急激な変化はおこらず，低級窒素化合物の増加は甚だ緩慢であることが以上の諸実験の結果明らかになった。しかるに，ウニ塩辛は製造後ほとんど時日を経ずに消費されはじめることを考えあわせると，このものは一般塩辛類におけるような顕著な熟成過程を必ずしも必要としないものといえよう。むしろ成分変化をつとめて避けて，新鮮な「生ウニ」の状態を保つことが，少なくとも浜詰製品では主たる目標とされているようである*。

一般に塩辛類の熟成は主として自家消化作用によって行われ，この作用は用塩量が少ない程さかんであるから低い食塩濃度下では熟成が速やかに進むが，10%程度の食塩濃度では自家消化のみならず腐敗が進行して貯蔵に耐えられないのが普通である[6]。しかるにウニ塩辛では，このような低い食塩濃度下でも成分変化が緩慢であるのは，同時に少量（12%前後）加えられるアルコールの作用に帰せられよう。すなわち，下関地方で行われるアルコールの添加は本来酵母による異常醗酵[7][8]を防ぐ目的ではじめられたものであるが，これは著しい静菌作用のみならず自家消化を阻害する作用をも有するので，成分の分解が甚だしく抑制されるわけである。

しかし，このような条件下においてもウニ塩辛の成分変化は徐々に進行し，1カ年にもわたる長期間の貯蔵後には相当の分解量に達していわゆる熟成の状態となる。この頃には化学成分の分解とともに，生殖巣の粒子の崩壊がおこってペースト状に近づく。したがって，長期間の貯蔵によって熟成が十分進行したウニ塩辛においては，呈味成分の増加と原料の均一な融和とによって円満な香味が附与される一方，軟化，融解のため淡白な新鮮さを失うに至る。このような極度の熟成は，時には賞用されることもあるが，一般に「粒ウニ」の品質としては粒状の保存が貴ばれるから当地方では避けられるのが普通である。しかしながら，ウニ塩辛でも製造直後よりもある程度時日を経た方が好まれるようである。これは，添加されたアルコール，食塩が原料生殖巣によく浸透融和し，アルコールの直接的な刺激臭がなくなり，さらに微弱な分解が加わって円満な味に落つくという程度の，軽い熟成が望ましいことを意味するものであろう。製造時には粒状の破壊を防ぐため強い混合，攪拌は極力避けられるが，このため製造後しばらくの間アルコール，食塩の分布は甚だ不均一のようであって，化学分析の各値もこのような初期には激しく不規則に変動し，これらがほぼ安定した値となるのは1カ月またはそれ以上の後のようである。恐らく，添加物が均一に浸透するにはおよそこれ位の期間を要し十分の食味が発揮されるのはこれ以後であることを示すものではなかろうか。

また，浜詰製品と量産製品とでは，用いられる原料自体にかなりの相違がある上，前者が新鮮状態において直ちにアルコールを添加されるのに対して後者は単なる塩蔵，冷蔵を施し後日アルコールを加えられるため，両者間には物理的にも化学的にも新鮮度の保持に明らかな差異がある。さらに，量産製品では，すでに凝塊となった原料が樽仕込みおよび壜詰めなどの操作によって攪拌されるため，粒状の保存は甚だ困難である。したがって，新鮮さの保持という前述の目標を基準とする限りでは，量産製品は浜詰製品に及ぶものではない。むしろ量産製品では，いわゆる熟成と調味とによって「生ウニ」の淡白さとは異なった濃厚な円熟味を附与することが一つの目標とされるべきであろう。

* この意味からすれば，熟成を必須の過程とする一般塩辛類とは区別すべきであって，「ウニ塩辛」なる呼称は不適当であるかも知れない。

アルコール，食塩は，また共に蛋白質を強く変性させるので，これらがウニ生殖巣の物性に与える影響は極めて重大と思われる。これらアルコール，食塩が品質に与える影響については次報において論ずる予定である。

摘　　要

下関地方におけるウニ塩辛（泥ウニ）を化学的ならびに微生物学的見地から研究して，次の結果を得た。

1）原料生殖巣は，ウニの種類，産地ならびに保存状態の相違などによって，成分にかなりの差異があった。

2）ウニ塩辛は，比較的低い食塩濃度にかかわらず貯蔵中急激な成分変化はおこらず，他の一般塩辛類におけるような顕著な熟成過程はみられなかった。これは，添加されたアルコールによって自家消化作用および微生物による分解作用が抑制されたためであろう。

本研究に当り，種種御指導を賜わった京都大学木俣正夫教授ならびに門田　元教授，および本報のとりまとめに際して有益な御助言を賜わった本所松沢定五郎教授に深謝する。また，実験の一部を分担された山本基夫氏ならびに寺崎　潜氏に謝する。研究費の一部は下関市水産振興に対する調査研究委託費によった。発表を許可せられた同市に対して謝意を表する。

文　　献

1）松井秀三郎・深山義道：1916．水講試験報告，**12**（3）．
2）島田　清・馬場良助：1933．日本水産学会誌，**1**，287．
3）清水　亘：1934．水産製造会誌，**2**，56．
4）長尾　清・木村　喬久：1951．水産学雑誌，**54**，21．
　————・————：1951．北大水産学部研究彙報，**1**，81．
5）長尾　清：1951．————，**2**，145．
　————：1953．————，**3**，259．
　————：1953．————，**4**，96．
　————：1954．————，**5**，47．
　————：1954．————，**5**，55．
　————：1954．————，**5**，62．
6）長崎　亀・山本　龍男：1954．日本水産学会誌，**20**，613．
　————・————：1954．————，**20**，617．
7）木村金太郎：1938．糧食研究，**142**，16．
　————・小谷　和夫：1927．水講試験報告，**22**，292．
　————・————：1940．糧食研究，**165**，178．
8）富安行雄・銭谷武平：1953．日本水産学会誌，**19**，585．
9）木俣正夫：1953．“水産講座（製造篇），”2巻．大日本水産会，東京，PP．53．

油なめし法の検討 其の二※

松沢定五郎・上田 正

Considerations on Oil Tanning —Ⅱ.※

By

Jōgorō Matsuzawa and Tadashi Ueda

Hydroshrinkage temperature (Ts) of the fatted skins are observed to shift to a higher or a lower temperature than the original skins'. Some factors, which effect to shift the treated skins' Ts, are researched by some simplified experiments. Their results are considered as follows;

a) Ts of the samples, which are tanned with oils in quite dry and cold circumstances, shift to a lower temperature (Tables 1 and 7).

b) Ts of the samples, which are treated with oils in a dry and warm condition, shift to a lower temperature still more (Tables 8 and 9).

c) Ts of the samples, which are wet and treated in a little wet condition, shift to a lower temperature slightly or hold their original state (Table 4).

d) Ts of the samples, which are wet and treated in a quite wet and warm condition, shift apparently to a higher temperature (Tables 3 and 7).

e) Ts of the fatted samples, which are soaked in water for 18 hours, shift regularly to a little higher temperature (Table 2).

f) The shift of Ts above mentioned is similarly observed in both cases of fish oils (sardine oil, cod liver oil) or their mixed fatty acids being applied in tanning. But, saturated, monoethenoid fatty acid, fish oil or its mixed fatty acids shifts the Ts of each fatted skin to a higher temperature in reverse order above mentioned, when treated in (e) condition (Table 14).

g) Fatted skins, treated with $K_2Cr_2O_7$ solution, heighten their Ts enormously. This heightening owes mainly to $K_2Cr_2O_7$ reacted by air-blow with mixed fatty acids, and not to seem to be the mixed fatty acids configured with $K_2Cr_2O_7$ (Tables 12—17).

h) Some of oil, applied in oil tanning, are fixed in the skin for 6 days, and a large portion of them exists free during that period. A certain portion of the free oil exists to act as tanning agent in the following period of tanning (Table 11).

i) Combination tanning of oil and formaline shifts Ts of its product to a wide range corresponding to the tanning agent applied in the last tanning. This fact is, however, observed in the case of dry skin being treated with mixed fatty acids

※ 水産講習所研究業績 第291号, 1959年11月2日受理
Contribufion from the Shimonoseki College of Fisheries, No. 291.
Received November 2, 1959.

in a dry condition (Tables 18 and 19).

此論文に於ては油剤を滲透せしめた皮（以下油皮と記す）の水熱収縮温度（Ts）を上昇或は下降せしめる条件を探究することを目的とした。

先ず四季に於ける処理成績を求め，それを考察した結果原皮の含水状態，油種，処理温度及び湿度等の影響を検討することを主題した。併せて重クロム酸カリ酸化法とホルマリンとの複合なめしにも触れた。

実験と其考察

（1）塩乾皮を低温低湿の環境下で（加油）—（風乾）を施行した場合

サメ塩干皮にイワシ油脂肪酸揮発油溶液を加脂し空気乾燥（風干）する。此両工程を10月21日より11月1日迄日日繰返しその後はその油皮を室内に放置した。その間適宜に Ts を測定した。此成果は第一表の通り。

Table 1. Products' Ts, resulted with the different concentration of mixed fatty acids from sardine oil. (in dry cold state).

No.	Tanning agents \ Date	Ts (°C) 21— Oct.	22— Oct.	24— Oct.	26— Oct.	29— Oct.	1— Nov.	6— Nov.	13— Nov.	22— Nov.	3— Dec.
1	Mixed fatty acids 1%	52.5	52.5	52.4	51.4	51.7	51.5	51.5	49.5	48.4	47.3
2	〃 10%	52.5	52.5	48.5	48	46.2	44	40.8	44.1	41.3	42.5
3	〃 25%	52.5	52.6	46.7	45.7	45.5	42.6	40.9	40.6	39.5	40.5
4	Petroleum	52.5	52.5	53.0	52.5	52.5	52.5	52.6	51	52	51.7
5	Liecithine (crude)	52.5	52.6	51.8	51.6	48.5	48.8	45.5	45.5	44	43

The samples are the salted and dryed shark skins. These are tanned with new tanning agents every day. Tanning agents are used in petroleum solution.

この成績を見ると No. 4 の Ts は終始殆んど変化がない。このことは揮発油は皮質（コラゲン）に何等の化学的変化を与えなかったものと考えられる。(此件については他に例証もあるが略す。)

No. 1，2 及び 3 即混合脂肪酸処理せるものは処理の進むに従ってその Ts は漸次下降している。そしてその下降の傾度をその濃度別に見ると高濃度程急である。

本処理条件を明記すると (イ) 秋冬季の低温低湿の環境下で (ロ) 原皮は塩干せるものを供用したのである。乾燥状態で魚油の混合脂肪酸を以て（加脂）—（風干）を反覆するとその油皮の Ts は下降するものと考えられる。

（2）半乾皮を高温低湿の環境下に於て（加油）—（風干）及び（水浸）を施行した場合

此実験の生皮床皮はその素干品を水戻しを為しそれに加塩脱水し，又サメ皮はその生皮に加塩脱水して供試した。

油剤としてはタラ肝油とその混合脂肪酸を，またその溶剤としてアセトーンと揮発油との等容混液を用いた。

処理は（加脂）—（風干）を日日繰返し，油剤を皮の内部に充分に滲透せしめた。最後の工程に於てその油皮を流水中に一夜浸漬（水浸）した。この処理期間は試料水分の蒸発が盛であった。

この成績を見ると（加脂）—（風干）工程中の Ts の移動は牛皮に於ては僅である。が，サメ皮に於ては下降の傾向がある。このことは油剤の種類による差がない。そして油皮を（水浸）する工程は原皮及び油剤の種別に関係なくその Ts を上昇せしめている。

本処理条件は夏季の (イ) 高温で低湿，(ロ) 原皮は塩皮即半乾の状態である。斯様な条件下で（加脂）—（

Table 2. Products' Ts, resulted with various tanning methods. (soaking in water).

No.	Date	Skin	Process	Tanning ageut	Ts(°C)	References
6	2—July—58	Ox hide	···	Cod liver oil 10 part	52.0	The sample is the inner layer of the hide, and salted, not dryed.
	3		Fatting—dry	Acetone 45 〃	51.7	
	4		Fatting—dry	Petroleum 45 〃	51.5	
	5		Fatting—dry		···	
	7		Soaked in running water overnight		56.0	
7	2—July—58	Shark skin	···	〃	51.9	The sample is salted, not dryed.
	3		Fatting—dry		49.8	
	4		Fatting—dry		49.7	
	5		Fatting—dry		···	
	7		Soaked in running water overnight		51.8	
8	2—July—58	Ox hide	···	Mixed fatty acids from cod liveroil 10 Acetone 45 Petroleum 45	52.0	The sample is the inner layer of the hide, and salted, not dryed.
	3		Fatting—dry		51.5	
	4		Fatting—dry		52.2	
	5		Fatting—dry		···	
	7		Soaked in running water overnight		57.8	
9	2—July—58	Shark skin	···	〃	51.9	The sample is salted, not dryed.
	3		Fatting—dry		49.7	
	4		Fatting—dry		49.4	
	5		Fatting—dry		···	
	7		Socked in running water overnight		50.7	

風干）を繰返すとその油皮の Ts は移動しないか或は幾分下降するものと考えられる。又（水浸）によって上昇することが見られる。この上昇は油脂の鞣剤化機構を考える時には注目に値する事実であろう。

（3）半乾皮を高温多湿の環境下に於て（加脂）—（湿干）を施行した場合

供試皮はサメ塩皮，油剤はタラ肝油とそれから製した混合脂肪酸とを用いた。

処理方法は二種で，その一は（加脂）—（風干），その二は（加脂）—（湿熱干燥）法である。（水浸）を何れの方法にも加えた。油剤と処理法と組合せで四種の試料を得た。

この成績を見ると四試料共処理の進行と共にその Ts は上昇している。そしてそれ等の上昇は油剤の又は処理方法の別による差は殆んどない。

又（水浸）工程によって明らかに Ts が上昇している。

本処理条件は梅雨季の (イ) 高温多湿，(ロ) 原皮は塩皮であるから半乾状態である。

斯様な条件下で皮に油剤を滲透せしめると（風干）によっても亦（熱湿干）によっても差がなく，何れも

Table 3. Products' Ts, resulted with the various tanning methods. (in rainy season)

No		10	11	12	13	
Date	Process	Ts(°C)				Process
		Cod liver oil	Fatty acids	Fatty acids	Cod liver oil	
24—June—58	Fatting—Air dry					Fatting—Dry in wet warm air
25	Fatting—Air dry	52.5	52.3	52.4	52.2	Fatting—Dry in wet warm air
26	Fatting—Air dry	53.3	54	55	54	Fatting—Dry in wet warm air
27	Fatting—Air dry	55.8	56.5	57.9	57	Fatting—Dry in wet warm air
	(set aside, rainy)	...	...	...	...	(set aside)
30	Fatting—Air dry	57.4	57.1	58.6	59	Fatting—Air dry
	(set aside)	...	...	...	...	(set aside)
2—July	(set aside)	58	58.3	58.5	58.9	(set aside)
3	Soaking in running water overnight	60.5	60	59.7	61.8	Soaking in running water overnight

Shart skin, salted: its Ts=52.2°C Fatty acids-mixed fatty acids from cod liver oil.

油皮の Ts は上昇するものと考えられる。又この条件下に於いても（水浸）工程は明に Ts の上昇に役立ている。注目すべきことである。

（4）半乾皮を高温中湿の環境下に於て（加脂）—（風干）を施行した場合

サメ皮は塩干皮，塩干皮より水戻ししたもの及びその水戻皮を加塩脱水した二種の状態のものを。牛床皮はその素干品より水戻ししたもの及びそれを加塩脱水した二種の状態のものを供試した。

油剤はイワシ油とその混合脂肪酸の二種とし，その溶剤にはアセトーンと揮発油を用いた。

Table 4. Products' Ts, resulted with various tanning methods. (in summer)

No.	Date	Skin	Tanning agent	Ts(°C)
14	26—Aug.—58	Shark skin, salted and dryed	Mixed fatty acids in petroleum	49.0
	27			46
	28			44
	29			44
15	26—Aug.—58	Shart skin, refreshd from salted one	〃	49
	27			50.8
	28			52.0
	29			48.1
	26—Aug.—58	Shark skin, salted	〃	49
	27			49.2
	28			52
	29			43.5

16	26—Aug.—58	Ox hide, refreshed	〃	51.5
	27			53.2
	28			54
	29			56.2
17	26—Aug.—58	Shark skin, salted and dried	Mixed fatty acids in acetone	49
	27			47.2
	28			44.1
	29			46.1
18	26—Aug.—58	Ox hdie, salted	〃	51.5
	27			56.5
	28			58.1
	29			56.9
19	26—Aug.—58	Ox hide, refreshed	〃	51.5
	27			55
	28			57.2
	29			60.9
20	26—Aug.—58	〃	Sardine oil	51.5
	27			54
	28			56
	29			50.3
21	26—Aug.—58	Shark skin, refreshed	〃	49
	27			52
	28			51.8
	29			56.7

処理は（加脂）—（風干）を日日繰返し油剤の滲透を充分ならしめた。その間適宜に試料の一部を切り取りその Ts を測定した。

この成績を見ると，油皮の Ts の移動は原皮の状態に上って異ている。即ち塩干皮に於ては下降し，塩皮及び水戻し皮に於ては上昇しているか又は一旦上昇しその後下降している。

本処理条件は夏季の (イ) 高温で中湿，(ロ) 原皮は塩干の半乾皮及び水戻皮の湿皮である。斯様な条件下で（加脂）—（風干）を繰返すと乾皮の場合は Ts が下降するものと，又半乾皮の場合は Ts が上昇し，最後に下降する。更に湿皮の場合は大体上昇を続けるものと考えられる。

上昇後の Ts の下降は試料が過乾に至った結果と推定される。

(5) 半乾皮を中温中湿の環境下に於いて（加脂）—（風干）を施行した場合

供試皮は犬生皮，犬塩干皮及び水戻しせるサメ皮である．油剤はイワシ油とその混合脂肪酸とである。前者はそのまま，後者は揮発油或はアセトーンを溶剤として使用した。

処理は（加脂）—（風干）を日日繰返して油剤の滲透を充分ならしめ，二十日以後は室内に放置した。その間適宜に Ts を測定した。

Table 5. Products' Ts, resulted with various tanning methods. (in autumn).

No.	Date	Skin	Tanning agent	Ts(°C)	References
22	10—Oct.—58	Dog skin, raw	...	61.3	Sardine oil; I.V. =176.2 A.V. =8.0～8.1
	13		Sardine oil	62.5	
	16			62.2	
	20			62.2	
	27			59.2	
23	10—Oct.—58	〃	Mixed fatty acids in petroleum		Mixed fatty acids are obtained from sardine oil; I.V. =182.1 A.V. =187.1
	13			61.7	
	16			61.5	
	20			57.5	
	27			56.2	
24	10—Oct.—58	〃	Mixed fatty acids in acetone	62.3	
	13			61.3	
	16			58.3	
	20			57.3	
	27			55.4	
25	10—Oct.—58	Dog skin salted and dried	Mixed fatty acids in petroleum	62.3	
	13			62.4	
	16			61.0	
	20			59.5	
	27			55.3	
26	10—Oct.—58	〃	Mixed fatty acids in acetone		
	13			62.4	
	16			61.9	
	20			59.3	
	27			55.5	

27	10—Oct.—58	〃	Sardine oil	
	13			62.4
	16			62.2
	20			59.5
	27			54.3
28	10—Oct.—58	Shank skin, refreshed from salted and dried	Sardine oil	51.4
	13			51.5
	16			51.3
	20			54.2
	27			49.2
29	10—Oct.—58	〃	Mixed fatty acids in petroleum	51.4
	13			51.5
	16			51.8
	20			52.0
	27			49.2
30	10—Oct.—58	〃	Mixed fatty acids in acetone	51.4
	13			48
	16			46.7
	20			46.5
	27			47.8

この成績を見ると水戻皮（No. 28, 29）は処理中 Ts は幾分上昇の傾向を示し又二十日以後の放置によって下降している。その他の水戻皮及び生皮即（No. 28, 29）以外の全部は下降の傾向を示している。

本処理条件は秋季の (イ) 中温中湿 (ロ) 原皮及び湿皮である。斯様な条件下で（加脂）—（風干）を繰返すと大勢的にはその Ts の移動は下降の傾向にあるものと考えられる。

（6）湿皮を昼間中温中湿夜間は低温低湿の環境下で（加脂）—（風干）を施行した場合

供試皮は塩干及びその水戻した犬皮で，油剤はイワシ油をアセトーンとアルコールとエーテルの混液及び揮発油の三種の溶剤に溶かして使用した。

処理は（加脂）—（風干）を日日繰返して油剤の滲透を充分ならしめ，その間 Ts を測定した。唯No. 39のみは最後の処理に（水浸）を施行した。

この成績を見ると供試皮が干皮のものは皆処理の進むに従って Ts が漸次下降している。但し試料を一夜流水中に浸漬即（水浸）するとその処理によって Ts は上昇し，又その後の処理によって他の同群と同様に下降している。

供試皮が湿皮の場合は皆等しく処理の初期に於て Ts は上昇し，後期に於て下降している。

Table 6. Products' Ts, resulted with various tanning methods. (in winter)

No.	Date	Skin	Tanning agent	Ts(°C)	References
31	5—Nov.—57	Dog skin, refreshed from salted and dried ones	Sardine oil in acetone	63.0	
	6			64.7	
	10			63.4	
	13			60.2	
	18			58.2	
	24			57.7	
32	5—Nov.—57	〃	Sardine oil in alcohole and ether	63.0	
	6			66.1	
	10			65.0	
	13			59.5	
	18			59.6	
	24			59	
33	5—Nov.—57	〃	Sardine oil in petroleum	63.0	
	6			64	
	10			62.7	
	13			59.6	
	18			59.2	
	24			58	
34	5—Nov.—57	〃	Sardine oil	63.0	
	6			63.6	
	10			63.9	
	13			60.5	
	18			58.6	
	24			56.4	
35	5—Nov.—57	Dog skin, salted and dried	Sardine oil in acetone	63.0	
	6			62.0	
	10			58.8	
	13			57.6	
	18			56.6	
	24			56.5	

36	5—Nov.—57	〃	Sardine oil in alcohol and ether	63.0	
	6			62.5	
	10			59.1	
	13			59.5	
	18			60.3	
	24			59.2	
37	5—Nov.—57	〃	Sardine oil in petroleum	63.0	
	6			59.5	
	10			56.1	
	13			55.1	
	18			56.4	
	24			57.3	
38	5—Nov.—57	〃	Sardine oil	63.0	
	6			62.2	
	10			59.5	
	13			59.5	
	18			61.5	
	24			60.7	
39	5—Nov.—57	〃	Sardine oil in acetone	63.0	
	6			61.5	
	10			64.0	Soaked in water
	13			63.8	
	18			61.0	
	24			59.2	

本処理の条件は冬季ではあるが室内暖房の為，(イ) 昼間は中温中湿夜間は低温低湿，(ロ) 原皮は干皮及び湿皮である。斯様な条件下で（加脂）—（風干）を繰返すと乾皮の場合はその Ts が下降し，湿皮の場合は初め上昇し後に下降するものと考えられる。

（7）湿皮を一定の高温多湿の環境下に於て（加脂）—（湿干）を施行した場合

供試皮は犬生皮とし，油剤はイワシ油，そのアセトーン液及び揮発油溶液の三つとした。

処理法は三つの方法によった。その一は（加脂）—（温湿干）—（水浸），その二は（加脂）—（風干）—（水浸）及びその三は（加脂）—（風干）である。

一定の温度及び湿度を得る為には特別の木箱を作り自働温度調節器を附属せしめた。調節精度は ± 2 °C

であった。

一定の湿度を得る為には下低の熱源と上部の試料棚との間に水盤を置きその水の蒸発によることとした。

Table 7. Products' Ts, resulted with various tanning methods. (warming & wetting)

Date	Process	Ts(°C) 40	41	42	No.
		Sardine oil in acetone	Sardine oil in petroleum	Sardine oil	Tanning agent
8—Jan.—58	(Dog skin, raw)	61.0	61.0	61.0	
～9	Fatting—Dry in warm(30°C), wet air				
9～10	—Soaking in water(30°C) —Fatting				
10～12	—Soaking in water(30°C) —Dry in wet air(30°C)	66.5	67.0	66.5	
13～16	—Soaking in running water				
～16	—Air dry	69.0	69.0	70.0	
～17	—Dry in air(30°C)—Soaking in water(30°C)	70.5	70.5	71.5	
～20	—Air dry				
～23	—Soaking in water(30°C)	70.0	70.0	71.0	

		43	44	45	No.
～9	Fatting—Airdry				
9～10	—Soaking in water(30°C) —Fatting				
～12	—Soaking in water(30°C)—Air dry	64.0	66.0	65.0	
～13～16	—Soaking in water(30°C)	66.5	70.0	98.0	
～16	—Air dry				
～17	—Air dry				
～19	—Soaking in water	68.5	70.5	69.0	
～20	—Air dry				
～23	—Air dry	69.5	70.5	70.5	

		46	47	48	No.
～9	Fatting—Air dry				
9～10	— 〃				
10～12	—Airdry	63.5	62.0	63.5	
13～16	— 〃	61.0	60.0	61.0	
16～19	— 〃	61.0	59	61.0	
～23	— 〃	61.0	59	60.5	

この成績を見ると処理法その一（加脂）—（温湿干）—（水浸）及びその二，（加脂）—（風干）—（水浸）によったものは処理の進行と共にその Ts は上昇を続けている。その上昇度を比較すると略同一であるが強いていえばその一法が幾分高めである。その三，（加脂）—（風干）によったものはTsが下降している。

本処理条件は二種と見做される。その一は処理法（加脂）—（風干）の場合でこれは (イ) 低温低湿，(ロ) 原皮は湿皮である。そのニは他の処理法の場合で (イ) 夏季の温度に近い30°C (ロ) 油皮を（水浸）すること及び (ハ) 原皮は湿皮である。そして処理法その一の条件では Ts は下降する。処理法その二の条件では上昇す

るものと考えられる。

なお（加脂）—（温湿干）—（水浸）法と（加脂）—（風干）—（水浸）法との成績が酷似していることを考えると，この場合では 30°C 水浸が油皮の Ts を上昇せしめる主要因と考えられる。

（8）湿度を一定高温（30—36°C）低湿下に於て（加脂）（温乾）を施行した場合

供試皮は水戻皮，油剤はイワシ油，そのアセトーン或いは揮発油溶液の三種である。

処理法は次の三種の方法によった。その一は（加脂）—（温干）その二は（加脂）—（風干）—（水浸）及びその三は（加脂）—（風干）を繰返した。但し温干は湿干箱中の水盤を去って行った。

Table 8. Products' Ts, resulted with various tanning methods. (warming to 36°C).

Date	Process	Ts(°C) 49	50	51	No.
		Sardine oil in acetone	Sardine oil in petroleum	Sardine oil	Tanning agent
11—Nov.—58	(Dogskin, refreshed)	61.0	61.0	61.0	
～12	Fatting—Dry in warm(30～36°C) air	58.0	58.8	61.5	
～15	— 〃	49.0	50.6	57.5	
～17	—Dry in warm air	49.0	47.0	54.0	

		52	53	54	No.
11—Nov.—58	Fatting—Air dry				
～12	— 〃	59.7	62.2	62.2	
～15	—Soaking in water—Air dry —Fatting	58.8	63.7	64.0	
～17	—Soaking in water—Air dry	61.0	63.5	64.5	

		55	56	57	No.
11—Nov.—58	Fatting—Air dry				
～12	— 〃	61.5	52.5	58.6	
～15	— 〃	62.5	61.5	58.7	
～17	—Air dry	59.5	59.5	59.0	

この成績を見ると処理法その一によったものは何れも Ts が下降している。その三即本実験以外の他の実験に於けると同様に Ts が下降している。そしてその一とその三との下降度を比較するとその一の方が急である。

処理法その二によったものは Ts が漸次上昇している。

本処理条件は次の三類と見做される。 その一類は冬季の低温低湿，(ロ) 原皮は湿皮。その二類は (イ) より低湿で高温，(ロ)原皮は同じく湿皮，(ハ) 油皮は（水浸）して吸水せしめてある。その三類は夏期の高温，低湿 (ロ) 原皮は湿皮である。

夫々の条件下で皮質と油剤との接触を図るとその一類の条件下では油皮の Ts が下降する。その三類の条件下では更に強く下降する。これは加温の為，油皮の乾燥が早められ過干状態になった為と考えられる。

その二類の条件下では Ts が上昇する。と考えられる。

（9）湿皮を高温（40°C）低湿下で（加脂）—（温干）を施行した場合

前実験と異る点は（温干）の温度を（40°C）に代えたことのみである。

Table 9. Products' Ts, resultad with various tanning methods. (warming to 40°C)

Date	Process	Ts(°C) 58 Sardine oil in acetone	59 Sardine oil in petroleum	60 Sardine oil	No. Tanning agent
2—Dec.—58	(Dog skin, refreshed)	61.0	61.0	61.0	
2～3	Fatting—Air dry	62.6	63.0	62.7	
4～5	—Soating in water—Air dry —Fatting	63.0	63.3	63.8	
～8	(set aside)	60.8	60.4	61.9	

Date	Process	61	62	63	No.
2—Dec.—58	Fatting—Air dry				
～3	—Fatting—Air dry	63.5	60.7	62.0	
～5	—Fatting—Air dry	63.5	60.5	62.5	
～8	(set aside)	62.0	57.0	61.0	

Date	Process	64	65	66	No.
2—Dec.—58	Fatting—Dry in air(40°C)	52.0	52.1	56.0	
～5	—Fatting—Dry in air(40°C)	43.3	43.4	47.3	
6～8	—(set aside)	41.1	42.5	44.8	

この成績を見ると（40°C温干）は（30～36°C温干）より強く Ts を下降せしめている。

(10) 湿皮を一定高温，多湿下に於て（加脂）—（温干）を反復した場合

供試皮は犬生皮，油剤はイワシ油，そのアセトーン或は揮発溶液の三種である。

処理方法は三類である。その一は（加脂）—（40°C湿干）—（30°C水浸），その二は（加脂）—（風干）—（30°C水浸），その三は（加脂）—（風干）である。

この成績を見ると処理法その一及びその二類に属する試料は夫々の処理の進行に伴って Ts は上昇しおる。

Table 10. Products' Ts, resultd with various tanning methods. (warm wetling iardry)

Date	Process	Ts(°C) 67 Sardine oil in acetone	68 Sardine oil in petroleum	69 Sardine oil	No. Tanning agent
24—June—58	(Dog skin, raw)	61.5	61.5	61.5	
24～26	Fatting—Dry in wet air (40°C)				
～30	—Soaking in water (30°C) —Dry in wet air (40°C)	66.5	67.0	66.5	
～31	〃	69.5	69.0	70.0	
～1—Aug.	—Soaking in water	70.5	70.5	71.5	
～2	—Air dry	70.0	70.0	71.0	

		70	71	72	No.
24～26	Fatting—Air dry—Soaking in water (30°C)				
～30	—Fatting—Air dry—Soaking in water (30°C)	64.0	66.0	65.0	
～31	—Air dry—Soaking in water (30°C)	66.5	70.0	68.0	
～1—Aug.	—Soaking in water	68.5	70.5	69.0	
～2	—Air dry	69.5	70.5	70.5	

		73	74	75	No.
24～26	Fatting—Air dry				
～30	—Fatting—Air dry	63.5	62.0	63.5	
～31	(set aside)	61.0	60.0	61.0	
～1—Aug.	(set aside)	61.0	59.0	61.0	
～2	(set aside)	61.0	59.0	60.5	

両法を比較すると大体同様であるが微差を求めるとその一類の方が幾分上昇度が高めである。その二類は他の四類の如く下降している。

(11) 油皮中の溶媒可溶性油のなめし能力

油皮中にある油脂は時日の経過と共にその一部は変性して油脂溶剤に不溶性となる。が，大部分は可溶性である。そしてこの可溶性油或不溶性油の何れが油皮のなめしに関連が深いかを考察する手掛として此実験を行った。

サメ塩干皮にイワシ油を以て（加脂）—（風干）を繰返して充分油剤を滲透せしめた。この所要日数は三日間である。この油皮を更に三日間放置した。この油皮をアセトーン或エーテルで連続抽出を行ってその可溶性油を遊離した。これ等の脱脂皮を（30°C）水で処理（水浸）した。これ等の工程毎に Ts を測定した。

Table 11. Products' Ts, resulted by disolving out their free fat.

No.		76	77	78
Date	Process	Ts(°C)		
		Controll	Fat removed by	
			Acetone	Ether
24—Feb.—57		49	48.5	47
26—	Treated with warm water	52.5	46.5	47
31—	Set aside	53.5	46.5	47
23—	Original skin	55.5	55.5	55.5

sardine oil is used.

この成績を見ると対称品（脱脂処理をせぬ油皮）の最終生産品の Ts が高く脱脂試料のそれは低い。なお詳しく見ると処理の初期即脱脂直後に於ける差は僅かである。その後の（温水浸）により Ts の差が甚しくなる。即ちこの処理により対称品の Ts は上昇し脱脂品のそれは不変（エーテル）が或下降（アセトーン）する。更にその後の放置により対称品は上昇し脱脂品は元のままである。

この事実は溶離された油脂中にもなお皮質と結合する能力を持ち得るものが残存することを示すものであろう。従って更に長時間両者の接触を図れば此結果と異る成績が得られる可能性がある。兎に角油剤が鹸剤化を完了するには相当の時日を要することも想定される。

又その他の考察については次報に譲る。

(12) 重クロム酸カリの効果

油なめしに於て油皮に $K_2Cr_2O_7$ 液を適用すると，その生産品の Ts を著しく上昇せしめることは久保田穣氏が発表した所である。この法を実施してみると処理法は簡易で効果は確実に著しい。その生産品の性状は油ナメシ皮よりはクローム革に近い。注目すべき製法と考えて若干の検討を行った。

（Ⅰ）重クロム酸カリ液の濃度

イワシ油より採製した混合脂肪酸を以て充分に滲透せしめたサメ皮の油皮を作る。これを細断（巾3mm 長3cm）して異濃度の $K_2Cr_2O_7$ 液に浸漬静置すること一夜にして（18h）後流水中で晒してその Ts を測定した。この成績は次表の通り。

Table 12. Ts, effected by soaking in the different concentration of $K_2Cr_2O_7$.

No.	1	2	3	4	5
$K_2Cr_2O_7$%	0	0.1	0.5	1.0	5
Ts(°C)	48.5	53.5	61.5	63.5	72.5

Original shark skin Ts=50.5°C
Soaking times=18h
Fatted shark skin Ts=48.5°C
Fatted shark skin's dimension=30mm×3mm×1.5mm (samples)

この成績を見ると各試料の Ts の差は驚く程大である。この実験は油皮の面積は略同一でありその他の処理条件は全く同一である。

本液処理による油皮の Ts の上昇は0.1%の如き低濃度に於ても5°C，5%では実に24°C上昇せしめいる。

（Ⅱ）浸漬時間

重クロム酸カリ液の濃度を5%とし，同一の油皮の略同一面積のものを浸漬（前実験と同様に）し，その時間を変えて Ts を測定した。

Table 13. Ts, effected by the times of soaking in $K_2Cr_2O_7$ solution(5%).

No.	6	7	8	9	10	11	12
Soaking times (h)	0	2.5	6.5	24	27	48	96
Ts(°C)	48.5	67.5	69.5	76.5	78.5	82.5	88.5

Original shark skin Ts=50.5°C
Fatted shark skin Ts=48.5°C
Sample dimension=30×3×1.5 (mm)

この成績を見ると浸漬時間が長くなるに従て Ts は高くなっている。

96時間に至てなおその効果を増している点を考えるとその効力の完了には長時間を要するものと見做される。

（Ⅲ）油皮の大さと油種

油皮をイワシ油。その混合脂肪酸，オレイン酸，及びステアリン酸の各で作り，得たる各種油皮の大さを変え且つその浸漬時間を変えて，5% $K_2Cr_2O_7$ 液中に処理して夫々の Ts を測定した。

Table 14. Ts, effected by its dimension and times for soaking various fatted skins.

No.	13	14	15	16
Soaking Times (hour) / Tanned with	47	18	47	71
Mixed fatty acids	85.5	73.5	78.5	84.5
Sardine oil	76.5	65.5	66.5	76.5
Oleic acid	66.5	61.5	61.5	64.5
Stearic acid	…	56.5	60.5	63.5
Dimension	Small piece 2×1.5×30 (mm)	Large piece 50×1.5×40 (mm)		

Original shark skin Ts=50.5°C

この成績を見ると油皮の大さの小さい方が大きものより短時間で Ts が上昇している。即ち小片の47時間と大片の71時間浸漬のものが略近い上昇度を示している。

又油種別に見ると油皮の油種別に効果の程度が異ている。即ちイワシ油混合脂肪酸のものが最大でステアリン酸のものが最低である。又この順序はその油剤の可変化性の序列と一致している。

(Ⅳ) なめし中の Ts に対する $K_2Cr_2O_7$ の効果

油なめし処理中その処理工程毎に その油皮の通常 Ts 及び $K_2Cr_2O_7$ 液を以て処理した Ts を夫々測定してみた。

Table 15. Ts, observed in progressive stages of oil tanning process.

No. 17

Date		22—June—59	25—June	30—June	9—July	15—July	27—July	8—Aug.
Process		Salted, dry shark skin	—Fatting —Air dry	—Dry by wet air	—Soaking —Dry by wet air	—Airdry —Fatting —Airdry	—Dry by wet air	—Dry by wet air
Ts	ordinary	49.5	47.5	48.5	56.5	49.5	50.5	53.5
	Treated with $K_2Cr_2O_7$ 5%	…	…	…	…	64.5	69.5	76.5

Dimension of the samples treated with $K_2Cr_2O_7$ sol.…2×1.5×30 mm
Soaking times …18 hours
Tanning agents…Mixed fatty acids from sardine oil.

この成績を見ると，その処理毎の油皮の Ts は $K_2Cr_2O_7$ 処理後のものがその通常 Ts より常に高い。このことは他の実験と同一傾向を示している。そして注目されることは両者の上昇度である。両者の上昇差は7月15日に於て 15°C，27日19°C，8月8日では23°Cとなって油皮のなめしが進むに従てその差が大となっている。

(Ⅴ) 新 $K_2Cr_2O_7$ 液と一度使用した残基の液

サメ塩干皮を新 $_2Cr_2O_7$ 液に又一度油皮の浸漬に使用した残基の $K_2Cr_2O_7$ 液に前記の皮を同様に浸漬してそれ等の Ts の移動を観察した。

Table 16. Ts, occurred in the soaking procese with new $K_2Cr_2O_7$ solution and its resudual.

No.		18	19	20	21	22	23
Soaking	solution	New solution (5 % $K_2Cr_2O_7$)			Resudual solution from the new(5%) solution used for soaking fatted skins		
	times (h)	0	18	18	0	6.5	96
Ts(°C)		50.5	55.5	57.5	50.5	54.5	71.5
Sort of skins		Salted dry skin		Fatted skin	Salted dry skin (shark)		

この成績をみると興味深い。

サメ塩干皮を新 $K_2Cr_2O_7$ 液中に浸漬したものが単にそれ丈けでその Ts は5°C上昇している。これ等の供試皮は脱脂工程を経ていない，従て皮中に幾分の油脂が残留している筈である。この油脂によるものが或は他の要因によるものかは判らない。又油皮を新液に同時間浸漬したものはそれより僅2°C高いに過ぎない。

サメ塩干皮を残基液（一度油皮を処理した $K_2Cr_2O_7$ 液）に96時間浸漬したものはその Ts＝71.5°C で元の Ts より21°C上昇している。このことは油皮と重クロム酸カリ液とを接触せしめるとその水性溶液中になめし能力のある物質が生成したことを示すものと考えられる。それで次の実験を行た。

（Ⅵ）イワシ油の混合脂肪酸と重クロム酸カリ液との反応液

10％ $K_2Cr_2O_7$ 液とイワシ油の混合脂肪酸とを丸底フラスコに容れ空気吹込攪拌を（Jul.—1959）20時間行た。その果成物を遠心分離（1500 rev/m：30 m）してその頂部の油脂部と底部の水性液部を分取する。中間の乳化部は揮発油を以て処理し再び遠心分離する。このものを乳化抽出液とする。この三種の液を以てサメ塩干皮を処理してその Ts を測定した。

Table 17. Ts, effected by the 3 parts of botutions, which resulted from $K_2Cr_2O_7$ solution reacted by air blow with mixed fatty acids.

No.		24	25	26	27
Tanning solution		Oily part	Aqueous part	Emulsion ext.	5%$K_2Cr_2O_7$
Ts(°C) Tanning times (h)	0	50.5	50.5	50.5	50.5
	24	47.5	70.5	50.5	55.5
	72	lower than 41.0	78.5	47.5	…
	96	…	82.5	…	…

Oily part…Saperated from the reacted solution by centrifuge(rev/m 1.500, 30m).
Aqueous part…　〃
Emulsion extract…Extracted by petroleum from the resudual emulsion of the above separation.

この成績を見ると，供試皮の Ts は油脂部処理より低下し，乳化抽出部もその傾向を示したのに水性液処理によっては Ts を甚しく上昇せしめている。

このことは脂肪酸と重クロム酸カリとの反応によって果成した水性液部になめし能力のある物質が出来たことを示すものであろう。換言すれば重クロム酸カリの変性によってなめし能力を生じたものであって脂肪酸の変性によるものでないと考えられる。

本実験では油性部は Ts 上昇に対し負に働いているが，しかし油皮中にあって皮質と結合している油脂が $K_2Cr_2O_7$ との反応により是と同じ作用をするか否かは別な問題であろう。

以上六つの実験成果から考えと久保田氏の指摘した如く，$K_2Cr_2O_7$ を油なめしに使用するとその還元物がなめしに干与していることが明に想定され，そして干与の程度は100 %に近いとも考えられる。

(13) 油剤とホルマリンとによる結合なめしをした場合の Ts の移動

供試皮はサメ塩干を用い，ホルマリンなめしは常法により，油なめしは塩干皮を（加脂）—（風干）法によって施行した。処理品は二つで処理の順序はお互の逆とした。

Table 18. Ts, changes where shark skin is tanned by formaline and followed with mixed fatty acids.

Tanning		Ts(°C)
Agent	Duration	
Formaline	1 day	75
	4	77.5
	6	77.5
Mixed fatty acids	1	74.5
	8	63
	17	57

original skin's Ts=50.5°C

Table 19. Ts, changes where shark skin is tanned by mixed fatty acids and followed with formaline.

Tanning		Ts(°C)
Agent	Duration(day)	
Mixed fatty acids	8	39.5
(Soaking in water)	1	34.5
Formaline	1	49
	3	55
	13	63.5

original skin's Ts=50.5°C

この成績を見るとホルマリン処理によって Ts は上昇しその後の脂肪酸処理によって低下する。又初めの脂肪酸処理によって Ts は低下その後のホルマリン処理によって Ts は上昇している。即ち後のなめし剤によって生産品の Ts が決定されている。

総　　括

油なめし工程を任意に変えて得た油皮の Ts を測定した。その結果から Ts を上昇或下降せしめる条件を検討した。その成果を総括すると次の通りである。

（a）乾皮に乾燥した環境下で油剤を接的せしめるとその温度，油剤の種類及び溶媒の種類に関係なくその Ts は下降する。高温（30—40°C にするとその下降は急になる。

（b）湿皮に徐々に乾燥する環境下（湿潤状態）で油剤と接的せしめると Ts は下降しないかあるいは下降しても僅かである。油剤及びその溶媒には関係が薄い。

（c）湿皮に高温（30　40°C）多湿の環境下皮と油剤とを接的せしめた場合では Ts は上昇する。

（d）油皮を（水浸）すると Ts が上昇する。このことは乾燥或多湿の環境下に於ても起る現象である。又実験範囲内の油剤の種類溶媒の如何に関係がない。

（e）油皮を $K_2Cr_2O_7$ 液処理すると著しく Ts を上昇せしめるが，この場合は油脂が鞣剤化したというよりは寧 $K_2Cr_2O_7$ が鞣剤化したことによると思われる。この実験に於ては油剤種類と Ts との上昇度とには明に関連が見られる。

（f）脂肪酸とホルマリンとの結合なめしに於てはその生産品の Ts は後の工程に用いたなめし剤の特性の影響を受ける。しかしこれは脂肪酸処理乾燥環境下で行った場合である。

文　献

1）久保田　穣：1958．油鞣に於ける反応規制因子の効果（第4報）．日本皮革技術協会誌，**2**（6），133～139．

牛乳カゼインのビンナガ鮪幽門垂プロテアーゼに依る分解生成物に就いて—Ⅰ.

該生成物の二十日ネズミに対する栄養試験※

藤井　実・小松次郎

Hydrolysis of Casein by Protease in Pyloric Appendage of Albacore *Thunnus Alalunga*—— I.
Nutritive Effect of the Mixture of Fragments from Hydyolyzed Casein on the Growth of the Mice.※

By

Minoru FUJII and Jirō KOMATSU

We hydrolyzed casein by protease in pyloric appendage of albacore *Thunnus alalunga* and obtained the mixture of fragments of hydrolyzed casein, which contained 18.7 % of proteose-nitrogen, 57.7 % of peptone-nitrogen and 20.9 % of polypeptide-nitrogen.

We made this mixture absorb into sweet potato or barley and made it dry.

These food manufactured by the above-mentioned method are called "Enriched food".

We observed the nutritive effect of this enriched food on the growth of the mice and obtained the results as follows: namely enriched food indicated a considerably nutritive effect on the growth of the mice as compared with the none enriched food and specially effective when we use it with vitamin B_6 injection.

緒　言

現在蛋白質栄養剤として市販せられているものには，各種のアミノ酸を適宜混合した製品や，カゼイン蛋白の分解生成物から出来ていると称する注射剤等がある。これらは経口的に或は静脈注射等により体内へ補給する。しかし注射剤は速効的ではあるが，病気等の非常時は別として常時注射により栄養剤を摂取することは，第一に煩雑であるばかりでなく，経済的にも決して容易でない。また径口的に服用する場合，これらのアミノ酸混合栄養剤は現在相当に高価であるから日常摂取することは，やはり経済的に相当の負担である。

※ 水産講習所研究業績　第292号，　1959年11月2日受理
Contribution from the Shimonoseki College of Fisheries, No. 292.
Received November 2, 1959.

このような観点から，人工哺乳或は栄養補給の一手段として牛乳を摂取する際，牛乳中の蛋白成分であるカゼインをそのまま摂取することなく，比較的簡易な方法でこれをより低分子の状態に変え，しかる後摂取せしめるならば，その消化吸収をより迅速に行わしめ，従って又，体組織蛋白への再編成を充分効果的に行い得るのではないかと考えられる。もしこのようなことが比較的低廉な費用で行い得るならば牛乳の栄養価を高め，従って国民体位の向上にも大いに役立つものであると考え，この実験を始めた。以上の観点から酵素剤として現在殆んど廃棄されている魚類内臓蛋白分解酵素を使用し二十日ネズミを試験動物として栄養試験を行ったのであるが，一応の成果を得たのでその結果について報告する。

実　験　の　部

試験動物：離乳後間もない体重6～10gの二十日ネズミを使用した。

強化蛋白食：5%カゼイン溶液40mlに粗酵素剤の水抽出液（粗酵素剤0.2gに相当）を添加して45°Cに一定時間反応せしめ，加水分解を行い，これに押麦（15g）又は乾燥甘藷（生芋20gに相当）を加えて加熱蒸発を行い，水分を除去すると同時に蛋白加水分解生成物を吸収附着させたものである。

対称食：カゼイン溶液を加水分解することなく，押麦又は乾燥甘藷に吸収附着させたもので，これには更に熱処理して不活性化した酵素液をも添加している。

これらを試験動物に給食する場合には更に無機物としてマツカラム塩[1]を4%，脂肪としてマガリンバター0.3g及びキャベツを適宜給与した。

1）鮪幽門垂プロテアーゼ（粗酵素剤）に依るカゼインの加水分解生成物について

5%カゼイン溶液40mlに該プロテアーゼ抽出液（粗酵素剤0.2gに相当）を添加しpH. 8.5，45°Cの条件で1時間及び2時間作用させた後三塩化酢酸を添加して酵素作用を止め，未消化カゼインを分離除去し，その濾液について分析を行った。即ち，濾液の一定量をとり，之から三塩化酢酸を除去した後，之に硫酸ナトリウムを飽和して生ずる沈殿をプロテオーズとして分離し，次にその濾液に燐タングステン酸を添加して生ずる沈殿をペプトンとして分離，残液中に含まれる窒素化合物をすべてポリペプチド態化合物とみなした。窒素の定量には硫酸分解法による外，Falin 試薬を使用して分光光度計による比色法を併用した。

実験結果の一例を示すと第1表の通りである。

Table 1. Digestion of casein by protease in pyloric appendage of albacore *Thunnus alalunga.*

Fraction / Digestive time(h)	Proteose-N (mg)	Peptone-N (mg)	Polypeptide-N (mg)	Non-digestive casein-N (mg)	Total-N (mg)	Digestion coefficient %
1	1.309	4.048	1.468	0.185	7.010	97.36
2	0.456	3.885	2.730	0.136	7.212	98.11

即ち，第1表の結果によれば，この実験条件で加水分解の時間が1時間の場合，カゼインの消化率は97%以上で，2時間分解では98%以上に達した。一定量のプロテアーゼによるカゼインの分解において加水分解生成量は一定の時間内においては，水解時間に比例的であることはこれまでの実験で明かである。従ってこの場合カゼイン態窒素は1時間の加水分解で殆んど完全に低次窒素化合物に変化せしめられているので，この分解条件でカゼインに対する酵素量は充分である。しかし加水分解生成物の内容は量的に相当の差異を生ずることは表の示す通りである。即ち，プロテオーズ及びペプトンの含量は1時間分解において76%，2時間分解においてはむしろ減少して62%となり，その代りに更に低級化合物（ポリペプチド）は後者が前者の2倍量を示した。またプロテオーズ及びペプトンも，それぞれ2時間分解の方が少く特にプロテオーズは約½に減少している。これはカゼインが充分存在する場合の分解とは逆である。（これに関しては次報で述べ

る）即ち，2時間分解の場合低分子化状態が1時間の場合のそれよりはるかに進んでいる。従って今いずれの分解液を試験に供すべきかが問題になるが，まず1時間分解液を試験に供することにした。

2）強化食の肥育強果

a）乾燥甘藷を使用した強化食

使用したカゼインは2gで，これに添加した乾燥甘藷の蛋白質は約0.27gである。動物を2群に分け，第I群に強化食を，第II群に対称食を与えた。実験結果は第2表及び第1図の通りである。

Table 2. Nutritive test of enriched food containing fragments from casein hydrolyzed by protease of pyloric appendage of albacore *Thunnus alalunga*. (animal : mice).

Group	Wt. initial (mean : g)	Wt. after 4 days (mean : g)	Wt. after 8 days (mean : g)	Wt. after 11days (mean : g)	Wt. after 11days / Wt. initial
I ♂2 ♀2	8.2	9.1	9.8	12.0	1.46
II ♂2 ♀2	9.2	9.7	10.2	11.0	1.20

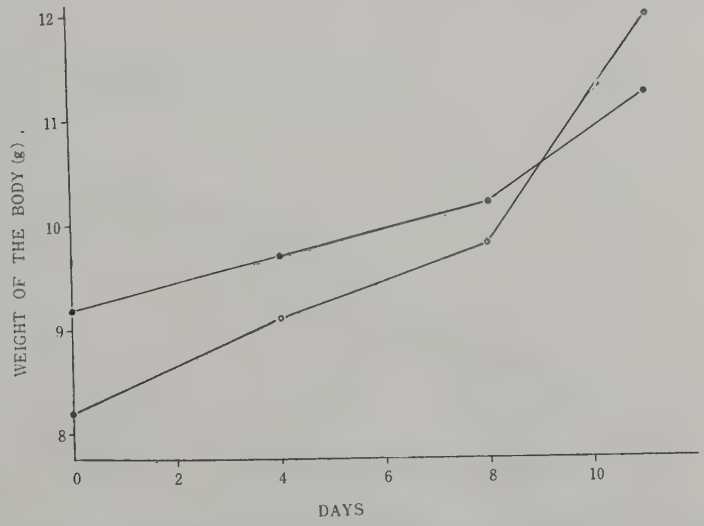


Fig. 1. Increase of the weight of the body of mice due to nutritive food. ○ : Enriched food, ● : Control.

即ち第I群の体重増加率は11日目に初期体重の46.3%（平均値…以下同じ）となっているのに対し第II群は約19.6%増となっていて，明かに第I群の肥育効果を認めることができる。

b）押麦を使用した強化食

強化蛋白質の吸着物質として押麦を使用したが，押麦は粗蛋白質を約9.6%含むものであるから，15gの押麦中には約1.4gの粗蛋白質を含有する。これに対し使用したカゼイン蛋白は2gであるから，前実験の飼料に比較すると相当の高濃度蛋白飼料となる。蛋白質及びアミノ酸の栄養試験に関しては多くの研究報告があり，高濃度蛋蛋白飼料の場合，ビタミンB6（V.B6）欠乏症状の発現が速くなり，死亡率も高まる

この報告がある[3]。また硫黄を含むシスチン，メチオニンのようなアミノ酸はＶＢ６欠乏を促進するといわれる[2]。従ってこの実験において強化食が高濃度蛋白飼料であるかどうかは別問題として，Ｖ．Ｂ６を給与することにした。またこのことはＶ．Ｂ₆の給与が強化食の価値を更に高めることができるか否かを推定し得ることにもなる。試験動物を３群に分け，第Ⅰ群に強化食及びＶ．Ｂ６，第Ⅱ群に対称食及びＶ．Ｂ６，第Ⅲ群には対称食のみとした。実験結果の１例を示すと，第３表第２図の示す通りである。

Table 3. Nutritive test of enriched food containing fragments from casein hydrolyzed by protease of pyloric appendage of albacore *Thunnus alalunga* (animal : mice).

Group	Wt. initial (mean : g)	Wt. after 3 days (mean : g)	Wt. after 7 days (mean : g)	Wt. after 9 days (mean : g)	Wt. after 9 days / Wt. initial
Ⅰ ♂1 ♀2	6.5	7.5	10.4	11.7	1.80
Ⅱ ♂1 ♀2	6.9	7.7	9.3	9.8	1.40
Ⅲ ♂1 ♀2	6.8	7.4	8.5	9.2	1.35

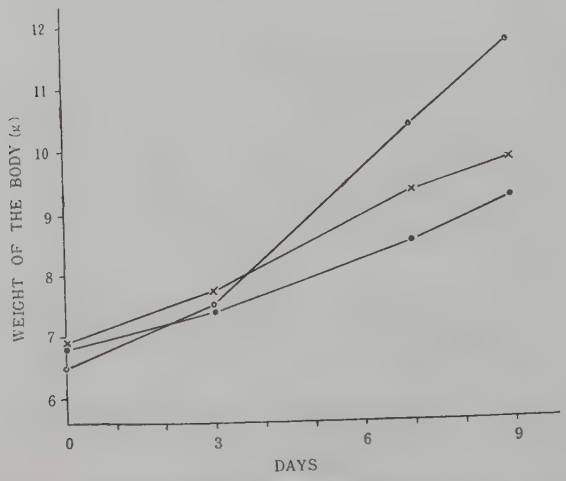


Fig. 2. Increase of the weight of the body of mice due to nutritive Food. ○ : Enricked food, Injection of vitamin B₆. × : Control, Injection of vitamin B₆. ● : Control, Non-injection.

即ち，試験開始後９日目において第Ⅰ群の体重は初期のそれの80 %増，第Ⅱ群：42 %増，第Ⅲ群：35 %増であった。

第２及び第３表は肥育試験開始後それぞれ11日及び９日目までの短期間における観測値である。しかしここには表示しなかったが，30日飼育の実験結果においても上記２表の結果と一致する結果を得た。即ち強化食は明かに肥育効果を有しているといえる。そしてＶ．Ｂ６の併用は更に強化の効果を高めるのに役立つようである。動物の栄養試験においては純粋な組成分のものを混合して飼育するのが常道であるが，我々は先

ず天然食に近い飼料で観察することにした。この場合種々の要因が交錯するので，その結果の判定に各種の問題を提起することが考えられるが，その反面，実際的な効果に近い結果をつかみ得ることと考えられる。しかして強化蛋白食のどのフラクションが最も有効的であるかということは次に行う詳細な実験にまつとして強化蛋白食は二十日ネズミの体重増加に著効を示し，その際V．B６を併用すれば更にその効果を高め得るという実験結果を得たことを報告するものである。

総　　括

牛乳カゼインを鮪幽門垂プロテアーゼにより加水分解して作った，いわゆる強化蛋白食を二十日ネズミに摂取せしめ，その肥育効果を検討した結果相当に有効であることがわかった。しかしてその際ビタミンB_6を併用することにより更にその肥育効果を高め得ることを認めた。この稿を終るに当り，試験動物を分譲して下さった九大農学部山藤研究室の方々に厚く御礼申上げます。また種々御高見を賜わりました九大教授富山博上に深謝いたします。またビタミンB_6の臨床実験例と，之に関して種々の有益な御意見を述べられた菊川病院長菊川博士に対し深甚の謝意を表します。

（この報告の大要は昭和33年の水産学会秋秋大会（於新潟）で発表した。

文　　献

1）鈴木梅太郎・井上兼雄：1946．栄養読本．日本評論社．
2）佐橋　佳一：1956．ビタミン学．金原出版株式会社．

A Tentative Analysis of the Distribution Pattern of Tuna Projected on the Long-line※

By

Hiroshi MAÉDA

Contents

Introduction 4
Acknowledgement 7
Historical 7
1. The outline of the tuna long-line fishery in Japan and the studies on tuna and tuna fisheries 7
2. Summaries of the biological studies done by using the similar method 8
1) Ecological works 8
2) Statistical works in the field of fisheries 10
Material and method 11
Preliminary consideration upon the existence of fish schools of large scales 16
Consideration upon the existence of schools having the width not exceeding the whole length of a row of gears 18
1. The basic assumption and the factors which should be taken into consideration 18
2. Constructing processes of the formulae used in the present study 19
1) The formulae representing the expected number of fish couples spaced by k section-intervals, when all individuals are scattered by chance 19
2) The formulae representing the expected number of fish couples spaced by k section-intervals, when catch rate increases with the soaking time 20
3) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the fishes are scattered by chance 22
4) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rate increases with the soaking time 23

※ Contribution from the Shimonoseki College of Fisheries, No. 293.
Received October 22, 1959.

5) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rate of hooks differs according to depth levels ····· 25
a) The formulae applicable to the gears with 4 hooks in each basket ····· 25
b) The formulae applicable to the gears with 5 hooks in each basket ····· 26
6) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rates increase with the soaking time and they differ according to the depth levels ····· 27
a) The formulae applicable to the gears having 4 hooks in each basket ····· 28
b) The formulae applicable to the gears having 5 hooks in each basket ····· 29
3. Analyses of the distribution pattern projected along the gears ····· 31
Notes for decoding the diagrams and notation used in them ····· 32
1) Big-eye tuna ····· 35
2) Yellow-fin tuna ····· 63
3) Albacore ····· 76
Comparison of the distribution patterns among the 3 species of tuna ····· 133
Consideration upon the spatial correlation between respectively yellow-fin tuna and big-eye tuna, tunas and marlins and tunas and sharks ····· 134
1. Construction of the formulae representing the expected number of the couples of individuals, respectively belonging to different species and spaced by k intervals ····· 135
1) The formulae representing the expected number of the couples of individuals, respectively belonging to different species and spaced by k section-intervals under the supposition that both species are distributed independently of each other ····· 135
2) The formulae representing the expected number of the couples of individuals spaced by k section-intervals, when the catch rate of each species shows gradient, but both species are distributed independently of each other ····· 136
3) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when individuals of both species are distributed independently of each other ····· 137
4) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when both species are distributed keeping some gradients ····· 138
5) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when the catch rate differs according to depth in both species ····· 139

6) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when the catch rate increases with the soaking time and differs according to depth in both species ····· 140
2. Analyses of the spatial correlation between individuals of two kind of fishes being distributed along the same row of gears ····· 146
1) Correlation between big-eye tuna and yellow-fin tuna ····· 147
2) Correlation between tunas and marlins ····· 162
3) Correlation between tunas and sharks ····· 170
Discussion ····· 177
1. Errors assigned to the fishing method ····· 177
2. Errors contained in the estimated values and the necessity of correcting the influence of the gradient ····· 183
3. Consideration upon the more advanced method—1. Interval method ····· 187
1) Uncorrected form ····· 187
2) The formulae in which the influence of the gradient of the catch rate is taken into consideration ($H=4$) ····· 188
3) The formulae in which the influence of the difference of the catch rate according to the depth is taken into consideration ($H=4$) ····· 189
4) The formulae in which the influences of both factors shown in sections 2 and 3 are taken into consideration ($H=4$) ····· 189
4. Further consideration upon the more advanced method—2. Analyzing method for the order of the arrangement of the intervals ····· 191
5. Consideration upon the factors affecting the gradient and the difference of the catch rate according to the depth ····· 192
1) Consideration upon the factors affecting the gradient of distribution ··· 192
2) Consideration upon the factors influential on the difference of the catch rate according to the depth ····· 197
Appendix: Application of the method proposed in this paper to the analyses of the data obtained by the different fishing methods ····· 201
1. Application to the analyses of the salmon population caught by gill-net ··· 201
2. Application to the analyses of the squid population caught by squid-traps ··· 203
3. Application to the analyses of the distribution pattern of the time when squids are angled under the fish-gathering lamp ····· 204
4. Application to the analyses of the distribution pattern of the time of the benthonic fishes being angled under the fish-gathering lamp ····· 206
5. Application to the analyses of the distribution pattern of the time when the fishes are angled in the day time along the shore ····· 208
6. Application to the analyses of the distribution pattern of benthonic fishes hooked along the coastal long-line ····· 208
Summary and conclusions ····· 212
References ····· 217

Introduction

Generally speaking, people are apt to consider the fishes have the tendency to form schools; and actually we often see a considerably compact schools of not only various pelagic but also some benthonic fishes. At the same time, however, it has been believed on the other hand, that the school formation is a general habit found in animals of rather lower food ranks and cannot be observed in the animals ranked at the higher trophic levels, which live usually solitarily and sometimes show the territorial habit. Notwithstanding the above-mentioned general conception, there are some cases in which marine animals of higher food ranks swim in schools as we see such facts in porpoise and sharks, both very active and voracious predators. Then, what is about tuna ? —— The tuna, which seem to be situated in a little lower food rank than sharks, but they are as large as the latter. It is believed by Japanese fishermen that the albacore is the only member of tuna, which swims in school, while grownups of yellow-fin and big-eye have never been observed swimming in school in the open sea except for several rare cases under such exceptional circumstances as swimming with whale or drift timber (for example, observable at Sagami Bay in summer) settling around reef (observable around the Bonin Islands) or attacked by porpoise, although they can occasionally be observed in the solitary state. Here lies, however, a question: whether they do not form any school really or they have the tendency to form schools, but we cannot discern it, because their schools are formed in the scale too big to be conceived as schools by our general conception of schools. Their high activity and so quick swimming ability seem to induce the requirement of a wide space for every tuna, consequently schools of an enormous scale beyond our general conception of schools might be formed without being easily discerned by people. Only a few papers have been published on the problems concerning this question: the details of the distribution of individuals within respective limited areas which we call fishing grounds, for instance a problem whether fishes are distributed uniformly, randomly or forming schools in the fishing ground under consideration, or that whether the difference of the density found among the different fishing grounds is simply attributable to the difference of the density itself or, besides it, also to the difference of the distribution pattern. On other items such as the geographical distribution of catch rate*, the relation between catch rate and oceanographical conditions and so on, all are very important and effective to find out good fishing grounds, many valuable works have been already published. Thus, the study to make clear the most detailed distribution pattern of tuna within respective fishing grounds or along respective long-lines seems to be one of the unexplored but fundamentally most important fields in fishery ecology, because it might give us chances to understand some theoretical bases for improving gears and

*The words "catch rate" used in this report indicate the occupied probability of a hook by individual of a certain species.

evaluating fishing grounds and for sampling method and the statistical transformation of many variates obtained by respective operations. Also it will be very helpful for us to find out some clues to solve questions about the social habits of fishes and the variabilities found in gonad maturity, age composition, stomach contents, the degree of radioactive contamination and many other biological phenomena observable among the individuals caught by a row of gears. Actually, however, we can hardly find any direct method to know the distribution pattern of tuna in deeper layers, sometimes reaching more than 100 m deep, in vast ocean; even if the problem is limited within the range of a single row of gears, the area should reach more than 50 km in extent. Most probably any of the experimental methods, if we could find them, cannot be easily put in practice, because the scale of the experiment is so big, and consequently too expensive to do. For these reasons, it seems to be a practical and effective way to adopt here such indirect theoretical methods as the analysis methods of the insect population to analyze the distribution pattern of tuna. In the following, I want to try the analysis of the distribution pattern of tuna by using such an indirect theoretical method and I am going to forward the work as a new unexplored branch of fishery ecology rather than a branch of statistics or mathematics.

To judge whether the fishes are forming schools or living solitarily, it is a very common way to make the examination of frequency distribution of individual numbers caught in respective sections, comparing the results with those induced from some theoretical distributions such as POISSON'S, binomial, PÓLYA-EGGENBERGER'S, NEYMAN'S, COLE'S, or THOMAS' ones. But this method shows the following defects that the sections in each of which no individual is caught or those in each of which many individuals are caught might occur successively or at random——; in other words, when the unit division is too large, the existence of small schools cannot be detected by statistical treatment, and contrarily when it is too small, the large schools may be divided into several partitions and the characteristics of the schools become quite obsolete. To fill up this deficiency, it is necessary to use some other methods in which a row of distributions is treated individedly as a continuous one. On this standpoint, the works of MURPHY and ELLIOT (1954) and MORISITA (1950, 1954 a, 1957 and M.S.) cited here seem to be appraised very highly. MURPHY and ELLIOT (1954) analyzed the above-mentioned relation by using the most probable number of runs, while MORISITA (1950) proposed a new trial —— one of the spacing methods —— for the analysis and illustrated the formulae representing the random movement or random distribution of individuals along the straight line, on the plane or in the space and applicable to the series of unit divisions in each of which from zero to infinite number of individuals can be included. And I also made an analysis of the distribution pattern of five species of salmons (dog, pink, red, silver, and king salmons) along the gill-net (1953) by using MORISITA'S formulae for the continuous series. However, in the case of treating the long-lines, there are some peculiarities that the points which can be occupied by individuals are distributed at regular intervals, the points $a(H+1)$ (here, H is the

number of hooks attached to a long-line in a basket and a is a positive integer) in the order from the first point are hypothetical ones incapable of being occupied by any individuals and, moreover, at each point only a single individual or none can be caught. Thus I was obliged to endeavour to establish new formulae applicable to the long-lines with such peculiarities mentioned above. I constructed the formulae applicable to the long-line having the same catch rates vertically and horizontally and analyzed the distribution pattern of yellow-fin tuna along the long-line by using these formulae (1955). The method adopted by MURPHY and ELLIOT (1954), and also the correlogram, don't seem to be available for the examples, in which the catch rate increases with the soaking time as pointed out already by themselves. Actually in a considerable number of examples offered by the professional or research fishing boats, the catch rate seems to increase with the soaking time. Even in the examples where the regression coefficient of catch rate on number of baskets or lots can not be regarded as significant, we often cannot but suspect the existence of a weak tendency of increase of the catch rate, although such increases can not be regarded as significant on account of their irregularity. Besides the fact mentioned above, they also pointed out that the tendency of schooling of tuna might probably be greater than that deduced from the analysis by using the most probable number of runs for the following four reasons: (1) some hooks may be occupied by fishes other than tuna, (2) the effect of the existence of buoy lines, (3) all the hooks are not situated strictly at the same depth and (4) the decrease of the potential sequence of tuna caused by stealing of bait by fishes other than tuna. By adopting the spacing method, effect of the existence of buoy lines can be removed by making an assumption and the influence of the increase of catch rate with the soaking time and that of the difference of the situation of hooks in depth can be corrected by constructing the formulae applicable to respective circumstances.

In this report, at first the constructing-processes of the theoretical formulae representing the chance distribution, which are used for the present analysis and mostly established newly, the analytical processes of the distribution patterns of some examples of yellow-fin tuna and big-eye tuna, both of which are thought as being distributed nearly by chance, and albacore, the young individuals of which are thought to form schools, and appendantly those of a few examples of sharks and marlins, which are located in higher food ranks than tuna and caught together with tuna, are illustrated. Then, in the last half, the analytical processes of the distribution patterns and the examples of the positional inter-relations between yellow-fin tuna and big-eye tuna, tunas and marlins or tunas and sharks are illustrated, as I found that such relations can be easily analyzed by using the same formulae as those adopted for the analyses in the first half and, moreover, such relations seem to be very interesting for us marine ecologists.

Acknowledgement

Before entering into the subject, I must express here my sincere thanks to Prof. Dr. D. MIYADI of the Zoological Institute of Kyoto University and Dr. T. TOKIOKA of the Seto Marine Biological Laboratory for their kind guidance and advices given to me during the present series of works. Also I want to record here my hearty thanks to Dr. A. L. TESTER of the Pacific Oceanic Fishery Investigations, Honolulu, Hawaii, U. S. A., Prof. Dr. S. UTIDA of the Entomological Institute of Kyoto University, Dr. M. MORISITA of the Biological Institute of Kyushu University, Prof. Dr. I. MATSUI and Prof. S. ERA of the Shimonoseki College of Fisheries, who assisted me much in giving facilities and many valuable advices which were all very effective and useful for carrying out this work and to Mr. M. SEKINO and any other staffs of the Shizuoka Prefectural Fisheries Station, Mr. T. UCHIDA of the Miyazaki Oceanic Fisheries Station and all the crews and cadets of the Dai-fuji-maru (a training boat of the Yaizu Fisheries High School) and the Shinyo-maru (a training boat of the Miyazaki Fisheries High School), who so kindly submitted their precious data to my study shown in the present paper. Thanks are also due to Japanese Tuna Fisheries Association who gave me helpful support through Prof. S. TSURUTA'S courtesy (Shimonoseki College of Fisheries) in publishing this article.

Historical

1. The outline of the tuna long-line fishery in Japan and the studies on tuna and tuna fisheries

Tuna long-line fishery, which is the most important method for fishing tuna in these days, has been prevalent since long ago in this country, although the operation had never extended beyond 25 miles off the coast before 1880 or thereabout. The application of modern internal combustion engines to the fishing boats, however, extended the fishing area to the unexpectable scale and also brought countless advances in the fishing system. In these days the tuna fishing boats over 500 tons and equipped with the radar, loran, magnetic auto-pilot *etc.*, are not rare in our country. These vessels go out for tuna fishing to the waters far east of the Hawaiian Islands, the waters near the Madagascar Channel or even to the Atlantic Ocean if some good catches can be expected there within a certain limit of time. Japanese fishermen can not hesitate to spend a considerably long time for the round trip to the fishing ground under present circumstances. The tuna fishing ground for Japanese fishermen thus has been extending year by year and now it covers nearly all the Pacific and Indian Oceans and even a part of the Atlantic Ocean.

NAKAMURA and his collaborators in the Nankai Regional Fisheries Laboratory, the staffs of the Kanagawa Prefectural Fisheries Station (1928—1959), SCHAEFER, SHIMADA, MURPHY and their associates in the Pacific Oceanic Fishery Investigations

and the Inter-American Tropical Tuna Commission in the United States (1950—1959), YOSHIHARA (1951—1957), KUROKI (1956) and some others have published many valuable ecological or technical papers on tuna and the tuna long-line fishery. In these papers, the seasonal change of the geographical distribution of tuna, the geographical differentiation of morphological or biometrical characteristics, the problems of the stock, the horizontal and vertical distribution of fishes along the long-lines, the relation between the catch rate and the oceanographical or meteorological conditions, the food habits, the improvement of gears and many other problems are explained extensively. Of these works, those closely related to my present study are quoted in respective parts of this report.

2. Summaries of the biological studies done by using the similar method

The works in which the biological distribution is analyzed can be classified into the following two groups: one comprises the works in which the distribution is examined for the purpose of deducing the social habits or the mechanisms of dispersion from the basic assumptions constructing the theoretical distribution applicable to the actually observed distribution —— in other words these are **Ecological works**, while the other includes the works in which the distribution is examined as merely a preliminary procedure of a certain statistical treatment other than the ecological purpose —— in other words these are **Statistical works**.

1) Ecological works

The early works in this field were done mostly by entomologists. BEALL (1935) is the first person who adopted the theoretical frequency distribution. Then, RICHARDS (1936) reported that the first generation of the common cabbage butterfly (*Pieris rapae*) is distributed at random while in the later generations than the second the distribution is biased from random; MARSHALL (1936) found that the egg masses of the American bollworm (*Heliothis obsolata*) are distributed by chance; BEALL (1940) estimated the frequency distribution of larvae of *Loxostege stictialis* on the supposition that their distribution might follow NEYMAN'S type A, B or C. UTIDA (1943) reported that the frequency distribution of number of eggs of Azuki bean weevil, *Callosobruchus chinensis*, on respective bean is hyponormal when the population density is low but it follows POISSON'S distribution when the population density is neither low nor so high, or it becomes hypernormal when the population density is clearly high. Recently UTIDA and his collaborators (1952—1957) published a series of comprehensive works on the field populations, in which it is stated that the distribution of eggs of common cabbage butterfly (*Pieris rapae*) follows PÓLYA-EGGENBERGER'S distribution, while its larvae are distributed according to a compound type of POISSON'S and binomial ones, that the frequency distribution of the rice-stem borer, *Chilo simplex*, in the paddy field follows PÓLYA-EGGENBERGER'S distribution under the estimation of the frequency distribution supposing that it follows POISSON'S distri-

bution, PÓLYA-EGGENBERGER'S or NEYMAN'S one of type A, that the frequency distribution of egg-masses of the spotted lady beetle, *Epilaclina sparsa orientalis*, follows POISSON'S distribution, and that the frequency distribution of the second or the third instars of larvae follows the distribution of NEYMAN'S type A but that of the fourth instar of larvae, pupae or adult beetles agrees well with the PÓLYA-EGGENBERGER'S distribution. And they deduced from these facts some knowledge upon the social habits and the mechanisms and processes of dispersal in these insects.

On the other hand, TORII (1952 and 1956) illustrated comprehensive and detailed descriptions of the estimating method for the distribution pattern of insect natural populations, in which he reported that the frequency distribution of egg-masses of *Promachurus yesoenus* born in the homogenous association in the lawn chiefly constituted of low-stemed Graminaceae follows POISSON'S distribution while that of those born on the barbed wire is hypernormal and then he estimated the frequency distribution of *Pyrousta nubialis* on the supposition that they follow the distribution of NEYMAN'S type A, B or C. He found also that the frequency distribution of *Anomala testaceipes* assembled each of 5 minutes around the lamp lighted for the first time follows convolute POISSON'S distribution, while it agrees with the POISSON'S one after the second night, and that the distribution pattern of *Stenocranus tateyamanus* living in the sedge vegetation may follow the gamma type of the compound POISSON'S distribution. He then analyzed the distribution patterns of many other insects by similar manner and gave careful consideration to the social habits and the mechanisms and processes of the distribution pattern and dispersal in respective cases.

COLE (1946) examined in detail the quantitative distribution of certain floor invertebrates —— spiders, isopods, diplopods and insects —— that live, among other place, under boards in the interface between the board and the ground, and found that spiders were only one group of animals which are distributed at random in all observational area for all seasons of the years, while for the other animals he constructed a type of convolute POISSON'S distribution and estimated the number of primary groups of respective size. Besides the above-mentioned works, many notable papers have been published by ROMELL (1930), BLACKMAN (1935), CLAPHAM (1938), ARCHIBALD (1948) and others on distribution of plants.

MORISITA (1950) noticed a considerable difference between the actually observed number and the estimated one when he compared the actually observed number of copulating pairs of *Gerris lacutis* with that estimated by using COLE'S distribution and proposed a new trial of spacing method, the details of which are already shown in the introduction of this paper. For the similar purpose, MURPHY and ELLIOT (1954) applied the analysis of sequence to the study on the distribution of yellow-fin tuna along the long-line, in which the most probable number of runs is determined from the total catch and the number of hooks.

As for other marine animals, YOSHIHARA (1953) analyzed the distribution of *Tectarius granularis*. KUROKI (1956) tried to estimate the size of albacore schools in the ocean. And I also analyzed the distributions of five species of salmons on the

gill-net in the waters about 100 miles east off Cape Lopatka (1953) by using the POISSON'S distribution, PÓLYA-EGGENBERGER'S and THOMAS' one together with the spacing method and gave some consideration to the unit of salmon population. And in my earlier paper of this series of the studies on the analyses of the distribution of tuna along the long-line, I proposed new formula for the spacing analysis amended so as to fit to the special conditions of the long-line gears and analyzed the distributions by using them.

Before closing this paragraph, it seems to be necessary to cite here two more papers which are estimated very highly for their theoretically excellent basic idea on the problem of probability. UMESAO (1950 a and 1950 b) analyzed theoretically the experimental population of tadpoles and proposed the term "interference" for a certain character causing the distributions in which the repulsive or attractive tendency among individuals is observable, and MORISITA (1952) proposed a method to represent quantitatively the different influences of the environmental conditions upon the habitat preference of animals by converting the effective value of environments for a certain animal into the population density of that animal.

2) Statistical works in the field of fisheries

YOSHIHARA (1952) reported that the frequency distribution of catches of trawlers operated in the waters east to 130° E. (unit: 10 days), yellow-tail set nets (unit: a day) or skipjack anglings (unit: 1 trip) follows the logarithmic normal distribution. KITAGAWA and YAMAMOTO (1950) reported that the mode of the frequency distribution of catches by bream long-liners or angling boats per boat and per month is biased to the lower side; while KESTEVEN and BURDON (1952) stated that the frequency distribution of catches by "*Kelong*" and "*Jaring Hanyut*" per trip follows also the logarithmic normal and they thought the distortion of mode to the lower side is more conspicuous in the operation of unmovile gears than in the case of movile gears and thus this tendency might be one of the characteristics of the fishing operated rather in the shore waters. And MAKO (1955) said that the frequency distribution of number of boxes, *ca.* 15 kg of each kind of several benthonic fishes are contained in each box, per haul on trawlers working in the East Chinese Sea and the Yellow Sea follows PÓLYA-EGGENBERGER'S distribution and hence arc sin transformation is more recommendable than the sq uare root transformation when the analysis method of variance is applicable to treating this material. On the other hand, YAMAMOTO (1956) made a comprehensive work on the unit catches (catch per trip) of nearly all of the important fisheries in Japan and stated in his paper that, generally speaking, the distribution curve of the unit catches of the trawling or the long-line fishery resembles the normal or logarithmic normal distribution, those of the fisheries using the echo-sounder or the fish-gathering lamp, such as purse seines, dip nets or angling, accord to the logarithmic normal or the ultra logarithmic normal distribution and that of drift net or beach seine set for the visiting fish schools at the fishing ground follows the exponential distribution. On these results he gave some consideration to the coefficient of variation in the unit catches and the stability of fishing, the relation

between the types of distribution of unit catches and the average catch per trip, the increase of tonnage of fishing boats and stability of fishing and factors influential on the quantity of catch per month in each fishing unit.

Besides the above-mentioned works, many other notable works were illustrated by BARNES and MARSHALL (1951), BARNES and BAGENAL (1951), SILLIMAN (1946) and WINSOR and CLARKE (1940).

Throughout the above-mentioned papers, however, the unit divisions adopted are fairly large as they are the total catches during one trip, those of a single boat per month, 10 days or a week or unit effort or haul. While in my papers, the unit divisions adopted are very small as they are respective sections of the gill-net, traps of the squid trap or hooks of the long-line; and so far as I am aware there is scarcely found the work in which such small divisions are taken up. Of course the unit divisions adopted in the statistical works by many authors are quite adequate for the purpose of the statistical investigations on fishing catches, but evidently seem to be too large for the studies of the distribution of fishes, which is the point we ecologists wish to know. As the studies of the distribution of fishes need more detailed data, the unit divisions should be smaller than one operation or haul, or rather the smaller they are, the better results are expected. Thus, the size of the unit division should be variable according to the purposes of the studies: —— either the distribution of catches is pursued as an ecological characteristic or as a preliminary step of the reasonable estimation of some variates of catches. The processes of treatment are superficially quite similar in these two groups of studies, although these two groups of studies differ essentially from each other. The necessity of the study on the distribution pattern of fish individuals along the gears is explained fully in the introduction already, but yet there is scarcely found such a work. It is very desirable that such studies will be investigated hereafter in the field of the fundamental biology as extensively as the distributions of catches in rather large unit divisions have been studied by this date in the field of the fishery statistics.

Material and Method

Each set of gears consists of *ca.* 360 main lines (a main line is usually represented in the word "a basket", because it is put in a basket when it is not in use) connected in a series and suspended in the water by buoy lines of 20 m long each attached at every joint. Each main line is 300 m long and provided with 4 or 5 branch lines of 25 m long set at regular intervals and each ending in a single hook. The interval between each pair of hooks on the same basket is from 50 to 60 m, while the interval between the distal hook of a certain basket and the adjacent one of the consecutive basket is from 100 to 120 m long. As the average buoy interval is shorter than the length of the main line in the actual operation, each main line of respective unit gears forms catenarian and thus hooks cannot be suspended at the same level but their situations are separated into two or three levels. The gears are set from one

end and it takes about 4 hours to empty the whole baskets. The setting is usually begun at mid-night, the boat is let drift for about 3 hours near the final end of the whole gears and then the hauling of gears begins from the final end of the whole gears. This time, it takes about 12 hours to haul up the whole gears. Thus the immersion of the whole gears lasts generally for three hours from about 3 *a.m.* to 6 *a.m.* in the dawn.

A half of the data used for the present study was offered by the Dai-fuji-maru and contains the data about albacores obtained in the waters near New Caledonia and the Solomon Islands during the period from Aug. 22 to Oct. 16, 1954 and those about yellow-fin tuna, big-eye tuna and the correlation between these two fishes obtained

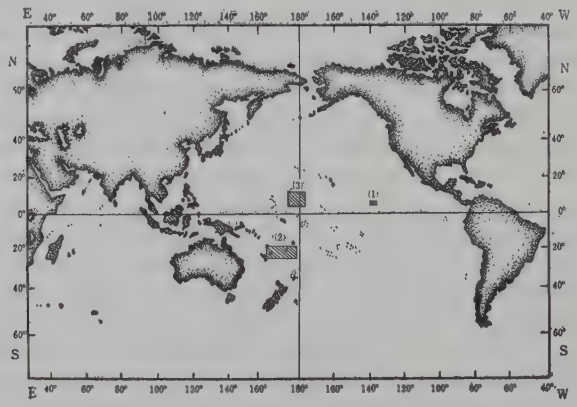


Fig. 1. Sketch chart of all fishing grounds under consideration.
Note : Numbers indicate the localities of the fishing grounds.

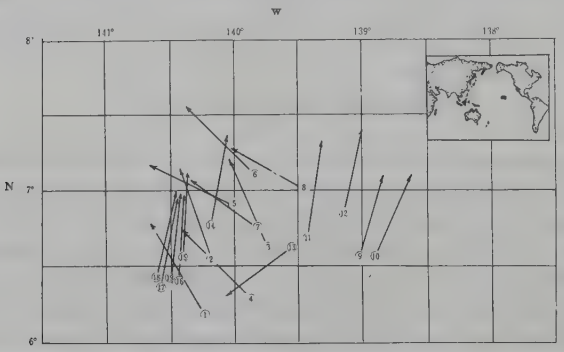


Fig. 2. Chart of Fishing Ground No. 1.
Notes : Arrows show the length and hauling direction of gears. Numbers represent the stations where the data about big-eye tuna and yellow-fin tuna and the correlation between these two fishes were obtained.

in the waters far east of the Hawaiian Islands during the period from Sept. 14 to Oct. 2, 1955, while another part was forwarded to me by the Shinyo-maru and includes the data about the correlation between tunas and marlins and that between tunas and sharks obtained in the waters east of the Marshal Islands during the period from Aug. 11 to Sept. 16, 1955. Sketch charts of the fishing grounds and the distribution of stations in respective fishing grounds are shown in Figs. 1—4. The situation of stations, number of gears used and the compositions of respective catches are given in Tables 1—3. Of these data, those about the operations, in which

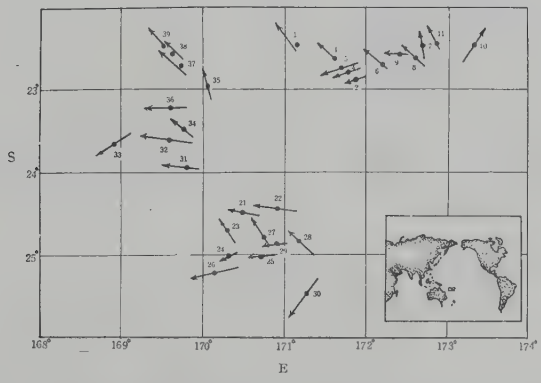


Fig. 3—1. Chart of Fishing Ground No. 2—1, 3 and 4.
Notes : Arrows show the length and hauling direction of gears. Numbers represent the stations where the data about albacore were obtained.

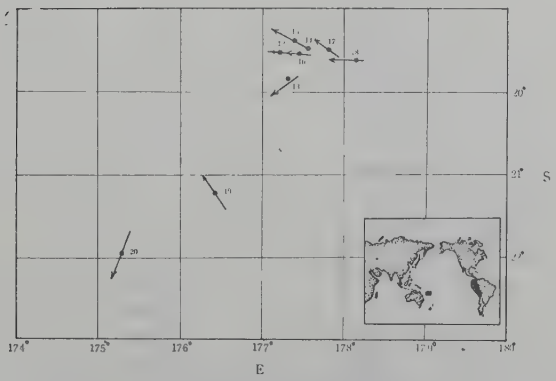


Fig. 3—2. Chart of Fishing Ground No. 2—2.
Notes are the same as in Fig. 3—1.

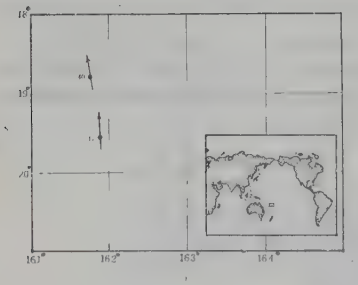


Fig. 3—3. Chart of Fishing Ground No. 2—5.
Notes are the same as in Fig. 3—1.

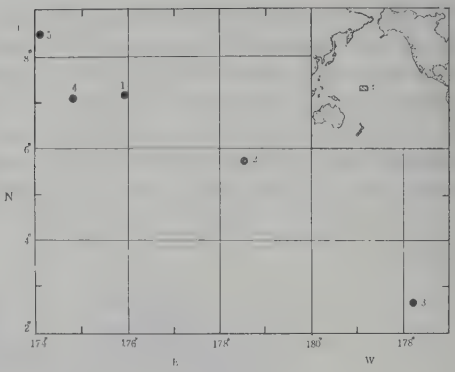


Fig. 4. Chart of Fishing Ground No. 3.
Note : Numbers indicate the stations where the data about the correlation between tunas and marlins or tunas and sharks were obtained.

Table 1. Position, number of gear used and catch composition at each station in Fishing Ground No. 1.

St.	Date	Position		Number of gear	Catch composition				
					Y.F.T.	B.E.T.	Marlins	Sharks	Others
1	Sept. 14, '55	6°29′ N	140°27′ W	364	**88**	**115**	10	29	5
2	15	6°51′ N	140°22′ W	357	**107**	**95**	14	24	7
3	16	6°58′ N	139°55′ W	341	**89**	**83**	12	14	5
4	17	6°30′ N	140°11′ W	352	**64**	**65**	8	21	3
5	18	6°59′ N	140°23′ W	358	**29**	**119**	6	29	5
6	19	7°20′ N	140°07′ W	359	**44**	**151**	14	13	6
7	20	6°53′ N	140°06′ W	362	**49**	**96**	12	14	7
8	21	7°08′ N	139°46′ W	360	**50**	**81**	7	22	10
9	22	6°50′ N	138°56′ W	360	**44**	**181**	12	14	14
10	23	6°52′ N	138°48′ W	355	**21**	**107**	12	22	4
11	24	7°02′ N	139°25′ W	358	3	**89**	26	36	6
12	25	7°06′ N	139°06′ W	351	15	**72**	12	23	6
13	26	6°36′ N	139°39′ W	354	7	**69**	15	28	7
14	27	7°03′ N	140°06′ W	356	14	**78**	17	32	8
15	28	6°50′ N	140°22′ W	357	23	**103**	16	26	15
16	29	6°40′ N	140°22′ W	358	13	**89**	9	31	5
17	30	6°37′ N	140°29′ W	359	17	**100**	26	39	3
18	Oct. 1, '55	6°27′ N	140°38′ W	359	11	**208**	24	16	4
19	2	6°26′ N	140°36′ W	317	21	**136**	10	21	8

The situation shown in the column of position indicates the point where the oceanographical observations were made and may be more or less apart from the start point of the hauling in respective operations. Y.F.T. : Yellow-fin tuna, B.E.T. : Big-eye tuna.

Table 2. Position, number of gear used and catch composition at each station in Fishing Ground No. 2.

Sub-fishing ground	St.	Date	Position		Number of gear	Catch composition				
						Albacore	Other tunas	Sharks	Marlins	Others
	1	Aug. 22,'54	22°21.0′ S	170°52.5′ E	356	**83**	14	9	16	0
	2	23	22°50.0′ S	171°48′ E	250	**119**	6	4	2	0
	3	24	22°36.9′ S	171°18.5′ E	350	**161**	9	4	4	2
	4	25	22°38′ S	171°19′ E	370	**142**	12	8	7	3
	5	26	22°51′ S	171°20.5′ E	380	**148**	12	6	8	3
1	6	27	22°55.5′ S	171°53′ E	380	**122**	14	6	10	7
	7	28	22°32′ S	172°36′ E	360	**110**	11	15	8	2
	8	29	22°38′ S	172°40′ E	388	**155**	8	8	5	3
	9	30	22°36′ S	172°29′ E	312	**97**	7	7	1	2
	10	31	22°28′ S	173°25′ E	370	**176**	6	1	8	1
	11	Sept. 1,'54	22°29′ S	177°57′ E	237*	**56**	7	7	7	4
	12	8	19°31′ S	177°12′ E	363	**92**	27	0	6	1
	13	9	19°53′ S	177°16′ E	374	**86**	28	23	6	4
	14	10	19°32.5′ S	177°28.5′ E	366	**62**	14	1	16	3
	15	11	19°27′ S	177°21′ E	364	**78**	30	18	10	3
2	16	12	19°34′ S	177°24′ E	367	**82**	25	1	14	3
	17	13	19°32.5′ S	177°46′ E	365	**29**	16	6	35	5
	18	14	19°49′ S	178°01′ E	330	**38**	20	4	15	3
	19	17	21°14.5′ S	176°25.5′ E	361	**58**	15	3	13	2
	20	18	21°57.5′ S	175°17′ E	330	**50**	13	1	12	0
	21	20	24°32′ S	170°30′ E	364	**117**	18	7	18	2
	22	21	24°32′ S	170°54′ E	346	**126**	24	0	12	2
	23	22	24°39′ S	170°22′ E	370	**97**	16	3	8	2
	24	23	25°01′ S	170°22′ E	368	**86**	12	0	17	4
3	25	24	25°03′ S	170°42′ E	370	**110**	13	2	14	3
	26	25	25°09′ S	170°08′ E	370	**72**	6	0	12	5
	27	26	24°50′ S	170°45′ E	367	**112**	7	6	16	3
	28	27	24°43.5′ S	171°09′ E	367	**79**	6	0	21	2
	29	28	24°53.0′ S	170°52′ E	366	**81**	6	7	8	5
	30	29	25°27′ S	171°17.5′ E	360	**76**	10	1	15	0
	31	Oct. 3,'54	23°59′ S	171°03′ E	362	**53**	44	8	8	2
	32	4	23°33′ S	169°23′ E	366	**75**	14	0	13	0
	33	5	23°38.6′ S	168°58′ E	370	**61**	2	7	17	1
	34	6	23°29′ S	169°46′ E	361	**71**	9	0	13	4
4	35	7	22°58′ S	170°00.5′ E	360	**74**	7	8	17	7
	36	8	23°13.8′ S	169°34.5′ E	370	**59**	8	0	13	2
	37	9	22°41′ S	169°40′ E	366	**105**	15	11	7	3
	38	10	22°34′ S	169°36.5′ E	370	**76**	7	0	22	4
	39	11	22°36′ S	169°31′ E	361	**59**	5	8	9	1

5	40	15	18°22′ S	161°54′ E	356	**47**	21	1	14	3
	41	16	19°46.5′ S	161°50′ E	370	**48**	25	4	5	10

Concerning the position, see the note under table 1.
* : Three hundred of baskets are soaked in all, but the baskets immersed after the 237th were entangled with the gears of the other fishing boat, and so they are omitted from the consideration.

Table 3. Position, number of gear used and catch composition at each station in Fishing Ground No. 3.

St.	Date	Position		Number of gear	Catch composition			
					Tuna		Marlins	Sharks
					Y.F.T.	Other tunas		
1	Aug. 11,′55	7°10.5′ N	175°57′ E	348	33	19	13	18
2	Aug. 15,′55	5°44′ N	178°34′ E	350	35	23	11	20
3	Aug. 18,′55	2°38′ N	177°46′ W	300	123	—	—	—
4	Sept. 4,′55	7°07′ N	174°48′ E	316	33		17	15
5	Sept. 16,′55	8°29′ N	174°06′ E	250	13		10	9

The position indicates the situation of the start point of setting gears.
Y.F.T. : Yellow-fin tuna.

the individual number caught in respective operations is not so large, are put aside the consideration, because the accidental errors of the observed values are too large in such cases. The data used in the further consideration are printed in gothic in tables.

Preliminary Consideration upon the Existence of Fish Schools of Large Scales

It is very natural to consider that the fishes are not distributed uniformly in ocean but their living areas are more or less limited; the largest scale of such limitations should be that of the geographical distribution. Further, it is also a well known fact that the uneven distribution of fishes occurs in the scale of a considerable extent which we call the fishing grounds. Indeed most of the efforts in the commercial fishing and the investigations on the distribution of tuna seem to be concentrated in finding any new or better fishing grounds. Then, are the distributions of various fishes quite uniform in respective fishing grounds ? Despite of the necessity to give answers to this question, the distribution pattern of fishes within the same fishing ground or within a series of gears seems to be still unclarified. The studies of the distribution pattern of fishes in the above-mentioned scale should be carried out in detail as well as the distribution in larger scales have been investigated. Thus, I began the studies to analyze the distribution pattern of fish individuals within the same fishing ground, especially that within a row of gears.

It is very doubtful that the aggregation of fishes as large in scale as the fishing ground constitutes a school, however large the fishes may be and however quickly

they can swim. If the fish schools of the scale larger than the fishing ground or beyond the extent of one operation cruise of fishing boats may exist, we cannot find any clue to detect the existence of such schools. But, if the fish schools which are within the scale of the extent of one operation cruise of fishing boats, but yet larger than a row of gears may exist, the catch rates at some stations should be abruptly higher than at others and the distribution of such stations should, in most cases, be limited within a certain part of the fishing ground. If many schools of considerable width may be caught partly overlapping one another, then it is inevitable that the width of the overlapping parts might be mistaken for the width of schools; although judging from the fact that the catch rates are very low and relatively homogenous all over the fishing grounds examined, the existence of such a phenomenon mentioned above seems quite unlikely.

In the actual observations, in the Fishing Ground No. 1, in the waters far east of the Hawaiian Islands, the catch rates of yellow-fin tuna at Stations 1～10 were higher than those at Stations 11～19. But this does not indicate that the stations showing higher catch rates are located within a certain area, because the Stations 11～19 were set in the same area covering Stations 1 to 10. The fishing boat moved at first from St. 1 to St. 10 (from west to east) along the current and then took her course against the current changing the stations from St. 11 to St. 19 (from east to west). The catch rates of big-eye tuna during the same period did not show any difference between the cruise along the current and that against the current. So, the existence of large schools of yellow-fin tuna or big-eye tuna, the width of which is smaller than the fishing ground but larger than a row of gears (longer than 50 km), cannot be expected in this fishing ground, because there is no definite evidence supporting the existence of any schools of such a scale. Only the possibility of the existence of schools of the scale shorter than a row of gears can be discussed on the data obtained in this fishing ground.

In the Fishing Ground No. 2, the catches of albacores showed the possibility of the formation of compact schools. The catch rates of albacore in the Fishing Ground No. 2—1,2 and 4 were higher than those in No. 2—3 and 5 and this seems to allude to the existence of a considerably large school of this fish, although it is some what doubtful that such large aggregations can be regarded as the school formation. If we may be admitted to regard them as schools, then their sizes estimated are as large as the extent of respective subdivisions of the fishing ground, namely 1° Long. × 3° Lat. (*ca.* 100 km× 300 km), 1° Long. × 1° Lat. (*ca.* 100 km× 100 km) and 2° Long. × 2° Lat. (*ca.* 200 km × 200 km), respectively. The data obtained in the Fishing Ground No. 3 don't seem to offer us any suggestions for the schooling, because the stations were not enough for the statistical treatment.

Then, in order to detect the existence of such schools, to estimate the mean width of the schools of the scale not exceeding the length of a row of gears and to clarify the spatial relation in detail as possible, the following analyses are pursued.

Consideration upon the Existence of Schools Having the Width not Exceeding the Whole Length of a Row of Gears

1. The basic assumption and the factors which should be taken into consideration

In a previous report of this series, I showed that the distance between the hooks and the composition of stomach contents are independent of each other. And the same relation is also known between the hook distance and gonad maturity or the former and the chemical properties of meat. During the Japanese Bikini Expedition held to research the after-influences of a series of atomic and hydrogen bombs, I met with the fact that the contamination degree by fission products was quite different in neighbouring individuals caught by successive hooks and sometimes some heavily contaminated individuals appeared when most of caught fishes were not contaminated at all or contrarily some non-contaminated individuals were found in some cases when most of fishes were heavily contaminated. Such phenomena seemed quite unreasonable for me at that time when I had kept already in my mind the possibility that yellow-fin tuna or big-eye tuna might swim in schools. The above-mentioned phenomena were frequently observed in a much large scale during the examination of the radio-active contamination of tunas and skipjacks landed at several main fishing ports in Japan. These facts may be explainable on the supposition that tunas are swimming almost solitarily. On the other hand, fishermen believe that they have seen neither the schooling yellow-fin tuna nor big-eye tuna larger than about 40 kg in body weight. Albacore and young yellow-fin tuna are said to swim in schools in the surface layer and caught some times by successive hooks in a manner as if it alludes to the existence of such schools, while spearfish or marlin, which are clearly seen swimming as solitary individuals in the surface layer, are always caught solitarily. Moreover, NAKAMURA (1949), MURPHY and ELLIOT (1954) and MURPHY and SHOMURA (1953) state out that there is no definite evidence of schooling habit of tuna living in the deeper layer, but there are many facts supporting their solitary life. For these reasons, the chance distribution should be accepted as the basic assumption of the theoretical distribution.

If most individuals are caught during the period when all units of gears are soaked, then the catch rate of all hooks at the same depth level must be throughout constant, while if a considerable number of individuals are caught during the course of setting or hauling, then the catch rates have to increase from one end to the other. Even in the latter case, if the population keeps the gradient of density opposite to the direction of increase of soaking time, the apparent distribution will take the form like that found in the former case. Actually, however, in so many examples, nearly all examples when emphasized, the catch rate of hooks increases with the soaking time. For such examples, the influence of the gradient of catch rate should be taken into consideration during the construction of formulae, otherwise the

results of further analyses will be much more contagious than the actual.

Besides the facts mentioned above, the average buoy interval is shorter than the main line in actual operations, consequently the main line of each unit of gear forms catenarian and all hooks are by no means situated at the same level, but the situations are differentiated into the two or three levels according to the number of hooks, 4 or 5. And it is a well known fact that the catch rate of hooks differs at different depth levels, being higher at deeper levels. When the catch rates of hooks at different depth levels are not the same, the hooks showing higher catch rate appear at regular intervals, consequently this might mislead to suppose the existence of schools arranged at the intervals as long as a basket. Thus, the effect of different catch rates of hooks at different depth levels should be taken into consideration, too.

2. Constructing processes of the formulae used in the present study

1) The formulae representing the expected number of fish couples spaced by k section-intervals, when all individuals are scattered by chance

Let us set that N individuals are scattered by chance in M consecutive sections of equal length. Probability of occurrence of each individual at each section is $\frac{1}{M}$. Then the probability of occurrence of any two individuals being caught within a certain section ($k=0$) is $\left(\frac{1}{M}\right)^2$. And the expected number of such case, $X_{(0)}$, is represented as follows, because there are M sections and the number of combinations picking up any two individuals among N individuals is $\frac{N(N-1)}{2}$:

$$X_{(0)}=M\frac{1}{M^2}\cdot\frac{N(N-1)}{2}=\frac{N(N-1)}{2M} \quad \cdots\cdots(1)$$

However, the expected number of two individuals (fish couples) being caught separately, one in a certain section and the other in the section spaced by k section-intervals, $X_{(k)}$ at $k\neq 0$, is represented as follows, the reasons are given below:

$$X_{(k)}=\frac{(M-k)N(N-1)}{M^2} \quad \cdots\cdots(2)$$

The probability of occurrence of a certain individual in the ith or the $(i+k)th$ section is $\left(\frac{2}{M}\right)$. Therefore, that of any two individuals caught in the ith or the $(i+k)th$ section is $\left(\frac{2}{M}\right)^2$. In this case, however, the probabilities of both individuals being caught together in the ith or the $(i+k)th$ section are included: these are respectively $\left(\frac{1}{M}\right)^2$. Thus, the probability of any two individuals being caught separately in the ith and the $(i+k)th$ section is $\left(\frac{2}{M}\right)^2-2\left(\frac{1}{M}\right)^2=\frac{2}{M^2}$. i can vary from 1 to $(M-k)$, and the number of combinations picking up any two individuals

among N individuals is $\frac{N(N-1)}{2}$.

Next formula is proposed by Dr. MORISITA (unpubl.) for the similar purpose, this is not yet published and I am very grateful to him for his kindness in permitting me to quote the formula before he publish it. By using this formula the probability of occurrence of other individuals within the $k'th$ section from any section occupied by a certain individual, when individuals are scattered by chance, is computable.

Probability $Q_{0-n}=\frac{(2k'+1)M-k'(k'+1)}{M^2}$

Actually observed value $X_{0-n}=\sum_{i=1}^{M-k'}(x_i\sum_{k'=1}^{k'}x_{i+k'})+\frac{1}{2}x_i(x_i-1)$

but $X_{0-}\frac{1}{2}x_i(x_i-1)$

(X_i: number of caught individuals in the ith section)

Number of combination $S=\frac{N(N-1)}{2}$

Observed probability $q_{0-n}=\frac{X_{0-n}}{S}$

$R_{0-n}\cdot\cdot\frac{q_{0\ n}}{Q_{0\cdot\cdot n}}$

Symbols are common to the formulae (1) and (2).

Here, it is easily noticed that the formulae (1) and (2) and $SQ_n=S\{Q_{0-n}-Q_{0-(n-1)}\}$ computed from MORISITA'S formula take quite the same value. But, in order to construct the formula in which the influence of the gradient of catch rate is taken into consideration it seems more convenient to adopt the formulae newly established.

2) The formulae representing the expected number of fish couples spaced by k section-intervals, when catch rate increases with the soaking time

Let us set that the number of individuals caught in the ith section is $N_i=(N_0+i\Delta N)$ and the total number of individuals caught by a row of gears constituted of M sections is $N=\sum_{i=1}^{M}N_i$.

The probability of a certain individual being caught in the ith section is represented as $P_i=\frac{N_i}{N}=\frac{N_0+i\Delta N}{N}=P_0+i\Delta P$.

In the same manner as in the construction of formulae (1) and (2), the probability of any two individuals being caught in the ith section is $(P_0+i\Delta P)^2$. And the expected number of such a case, $X_{(0)}$, is represented as follows, because i can vary from 1 to M.

$$X_{(0)}=\frac{N(N-1)}{2}\sum_{i=1}^{M}(P_0+i\Delta P)^2$$

$$=\frac{MN(N-1)}{2}P_0^2\left[1+(M+1)\delta+(M+1)(2M+1)\frac{\delta^2}{6}\right]\cdots\cdots\cdots\cdots(3)$$

here $\delta = \frac{\Delta P}{P_0}$

because

$$\sum_{i=1}^{M} (P_0 + i\Delta P)^2 = \sum_{i=1}^{M} (P_0^2 + 2P_0 \Delta P i + \Delta P^2 i^2) = P_0^2 \sum_{i=1}^{M} (1 + 2\delta i + \delta^2 i^2)$$

$$= P_0^2 \left[M + \frac{2(M+1)M}{2} \delta + M(M+1)(2M+1)\frac{\delta^2}{6} \right]$$

$$= MP_0^2 \left[1 + (M+1)\delta + (M+1)(2M+1)\frac{\delta^2}{6} \right]$$

Probability of occurrence of a certain individual in the *ith* or the $(i+k)th$ section is $(P_0 + i\Delta P) + (P_0 + i + k\,\Delta P)$; therefore that of any two individuals being caught in the *ith* or the $(i+k)th$ section is $\{(P_0 + i\Delta P) + (P_0 + \overline{i+k}\,\Delta P)\}^2$, but here the probabilities of both individuals being caught together in the *ith* or the $(i+k)th$ section are included, which are respectively $(P_0 + i\Delta P)^2$ and $(P_0 + \overline{i+k}\,\Delta P)^2$. Thus, the probability of any two individuals being caught separately in the *ith* and the $(i+k)th$ section is

$$\{(P_0 + i\Delta P) + (P_0 + \overline{i+k}\Delta P)\}^2 - (P_0 + i\Delta P)^2 - (P_0 + \overline{i+k}\Delta P)^2$$
$$= 2(P_0 + i\Delta P)(P_0 + \overline{i+k}\Delta P)$$

i varies form 1 to $M-k$. Accordingly, for the same reasons mentioned previously in the construction of formula(2), the expected number of any two individuals being caught separately in two sections spaced by k section-intervals, $X_{(k)}$, is given as follows:

$$X_{(k)} = \frac{N(N-1)}{2} \times 2 \sum_{i=1}^{M-k} (P_0 + i\Delta P)(P_0 + \overline{i+k}\Delta P)$$

$$= MN(N-1)P_0^2 \left[1 + (M+1)\delta + (M-k+1)(2M+k+1)\frac{\delta^2}{6} \right] \cdots\cdots (4)$$

here $\delta = \frac{\Delta P}{P_0}$

because

$$\sum_{i=1}^{M-k} (P_0 + i\Delta P)(P_0 + \overline{i+k}\Delta P) = \sum_{i=1}^{M-k} \left\{ P_0^2 + 2(i+k)\, P_0 \Delta P + i(i+k)\Delta P^2 \right\}$$

$$= P_0^2 \sum_{i=1}^{M-k} \left\{ 1 + (2i+k)\delta + i(i+k)\delta^2 \right\}$$

$$= P_0^2 \sum_{i=1}^{M-k} \left\{ (1 + k\delta) + (2\delta + k\delta^2)i + \delta^2 i^2 \right\}$$

$$= P_0^2 \left[(M-k)(1 + k\delta) + \frac{(M-k+1)}{2}(M-k)(2\delta + k\delta^2) \right.$$

$$\left. + (M-k)(M-k+1)(2M-2k+1)\frac{\delta^2}{6} \right]$$

$$= P_0^2 (M-k) \left[1 + (M+1)\delta + (M-k+1)(2M+k+1)\frac{\delta^2}{6} \right]$$

The general tendencies of the theoretical values computed from four above-mentioned formulae are shown in Fig. 5.

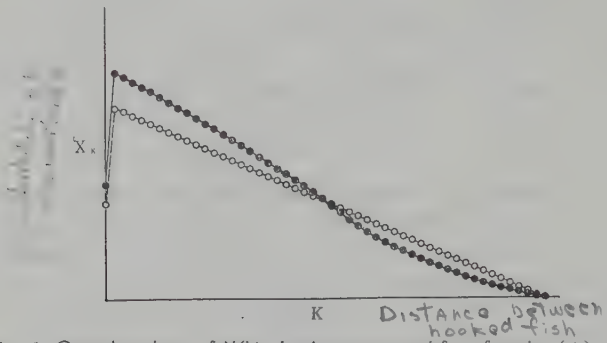


Fig. 5. General tendency of X(k)—k relation computed from formulae (1)—(4). Notes: White circles indicate the values computed from formulae (1) and (2), in which the influence of gradient of catch is put out of consideration. Filled circles show the values computed from formulae (3) and (4), in which the influence of gradient of catch is taken into consideration.

The formulae (1) and (2) can be derived from MORISITA'S formula applicable to the connected series of sections, while the formulae (3) and (4) are constructed for the purpose of taking the influence of the gradient of catch rate into consideration. Accordingly the latter two are applicable to the connected series of sections of equal width, in each of which from 0 to one or more individuals can be caught. When the unit length under the consideration is diminished as possible ultimately to 1 hook-interval (the word "hook-interval" used in this report indicates the mean interval between any two consecutive hooks located in the same basket), the conditions become similar to the peculiar conditions characteristic to the long-line gears as mentioned previously. Besides this, another factor, the influence of the different catch rates of hooks situated at the different depth levels must be taken up as the factor to be taken into consideration. Thus, there arises the necessity of constructing new formulae applicable to such a peculiar conditions, in which the influence of each or both of the difference of the catch rate due to the increase of soaking time and that caused by the difference of the depth level of hooks is taken into consideration.

3) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the fishes are scattered by chance

Let us set that N individuals are scattered by chance along a row of gears, which consists of m consecutive baskets of equal length and having H hooks respectively. k is represented as $k=a(H+1)+R$, when it is separated into the part divisible by the length of a basket and the remainder. Then the hooks spaced by k

hook-intervals from respective hooks in the *ith* basket are represented as shown in

Table 4. The hooks spaced by k hook-intervals from respective hooks in the *ith* basket ($H=4$).

R \ h	1	2	3	4
0	1	2	3	4
1	2	3	4	B
2	3	4	B	1′
3	4	B	1′	2′
4	B	1′	2′	3′

Note : h is hook number in the *ith* basket.
B indicates buoy-line.
k is represented by $a(H+1)+R$
1 : the first hook in the $(i+a)th$ basket.
1′: the first hook in the $(i+a+1)th$ basket.

Table 4. Here, a is a positive integer varying from 0 to m, while R varies from 0 to H. When $R=0$, there are H hooks in the $(i+a)th$ basket spaced by k hook-intervals from respective hooks in the *ith* basket (i varies from 1 to $m-a$), but no hook can exist in the $(i+a+1)th$ basket (i varies from 1 to $m-a-1$). When $R \neq 0$, however, there are $(H-R)$ hooks in the $(i+a)th$ basket spaced by k hook-intervals from respective hooks in the *ith* basket and besides there are $(R-1)$ hooks in the $(i+a+1)th$ basket. On the other hand, the probability of each hook being occupied by fish is $P=\frac{N}{Hm}$, and the probability of any two hooks being occupied by fishes is P^2.

Accordingly, the expected number of two hooks spaced by k hook-intervals being occupied by fishes, $X_{(k)}$, is shown by the following formulae:

at $R=0$

$$X_{(k)}=H(m-a)P^2 \quad (5)$$

at $R \neq 0$

$$X_{(k)}=\{(H-1)(m-a)-(R-1)\}P^2 \quad (6)$$

The values theoretically computed by using these formulae decrease gradually with the increase of k; $X_{(k)}$ takes the same value at $k=a(H+1)+H$ and $k=(a+1)(H+1)+1$, while at $k=(a+1)(H+1)$ it is approximately $\frac{H}{H-1}$ times the value computed at $k=a(H+1)+H$ and $k=(a+1)(H+1)+1$.

4) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rate increases with the soaking time

Let us set that k is represented by $k=a(H+1)+R$ in the same way as in the preceding paragraph, N individuals are distributed in m consecutive baskets respectively equipped with H hooks, and the catch rate shows some gradient. As for the gradient of catch rate, P_0 and ΔP are defined as that the catch rates of a

hook in the *ith*, the $(i+a)th$ and the $(i+a+1)th$ baskets are represented respectively by $(P_0+i\Delta P)$, $(P_0+\overline{i+a}\,\Delta P)$ and $(P_0+\overline{i+a+1}\,\Delta P)$, in other words $N=H\sum_{i=1}^{m}(P_0+i\Delta P)$. Therefore, the probability of two hooks being occupied by fishes, one of which is found in the *ith* basket and the other is spaced by k hook-intervals from the former, takes $(P_0+i\Delta P)(P_0+\overline{i+a}\,\Delta P)$ or $(P_0+i\Delta P)(P_0+\overline{i+a+1}\,\Delta P)$. Accordingly, the expected number of two hooks spaced by k hook-intervals being occupied by fishes, $X_{(k)}$, is represented by next formulae:

at $R=0$

$$X_{(k)}=H\sum_{i=1}^{m-a}(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)$$

$$=HP_0^2(m-a)\left[1+(m+1)\delta+(m-a+1)(2m+a+1)\frac{\delta^2}{6}\right]\cdots\cdots(7)$$

at $R\neq 0$

$$X_{(k)}=(H-R)\sum_{i=1}^{m-a}(P_0+i\Delta P)(P_0+i+a\Delta P)+(R-1)\sum_{i=1}^{m-a-1}(P_0+i\Delta P)(P_0+i+a+1\,\Delta P)$$

$$=P_0^2\Big[\{1+(m+1)\delta\}\{(H-1)(m-a)+1-R\}$$

$$+\{(H-R)(m-a)(m-a+1)(2m+a+1)$$

$$+(R-1)(m-a-1)(m-a)(2m+a+2)\}\frac{\delta^2}{6}\Big]\cdots\cdots(8)$$

here $\delta=\dfrac{\Delta P}{P_0}$

because

$$\sum_{i=1}^{m-a}(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)=\sum_{i=1}^{m-a}\{P_0^2+(2i+a)P_0\Delta P+i(i+a)\Delta P^2\}$$

$$=P_0^2\sum_{i=1}^{m-a}\{1+(2i+a)\delta+i(i+a)\delta^2\}=P_0^2\sum_{i=1}^{m-a}\{(1+a\delta)+(2\delta+a\delta^2)i+\delta^2i^2\}$$

$$=P_0^2(m-a)\left[1+(m+1)\delta+(m-a+1)(2m+a+1)\frac{\delta^2}{6}\right]$$

and

$$\sum_{i=1}^{m-a-1}(P_0+i\Delta P)(P_0+\overline{i+a+1}\,\Delta P)$$

$$=P_0^2(m-a-1)\left[1+(m+1)\delta+(m-a)(2m+a+2)\frac{\delta^2}{6}\right]$$

The values of $X_{(k)}$ theoretically calculated from this type at k which represents not so large intervals are a little higher than those estimated by using the formulae (5) and (6), although the outline of the variation with the increase of k is quite the same as that found in the former type except for the fact that the rate of decrease with the increase of k is sharper than in the case estimated from the former formulae.

5) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rate of hooks differs according to depth levels

The formulae illustrated in the preceding two paragraphs are applicable to any long-line gears, being quite irrespective of number of hooks attached to each basket; while those shown in the following two paragraphs vary according to the number of hooks attached to each basket. Next, two groups of formulae applicable to the long-lines respectively with 4 and 5 hooks in each basket are illustrated as examples.

a) The formulae applicable to the gears with 4 hooks in each basket

Let us set that N_1 and N_2 individuals are scattered by chance respectively at the shallower and deeper hooks in a row of gears constituted of m consecutive baskets.

Table 5. Catch rates of respective hooks shown in Table 4 ; here the influence of the catch rate varying according to the depth level of respective hooks is taken into consideration ($H=4$).

R \ h	1	2	3	4
	P_1	P_2	P_2	P_1
0	P_1	P_2	P_2	P_1
1	P_2	P_2	P_1	0
2	P_2	P_1	0	P_1
3	P_1	0	P_1	P_2
4	0	P_1	P_2	P_2

Table 6. Probability of both of the two hooks related with each other as shown in Table 4 being occupied by tuna; here the difference of the catch rate due to the different depth levels of respective hooks is taken into consideration ($H=4$).

R \ h	1	2	3	4
0	P_1^2	P_2^2	P_2^2	P_1^2
1	$P_1\ P_2$	P_2^2	$P_1\ P_2$	0
2	$P_1\ P_2$	$P_1\ P_2$	0	$\mathbf{P_1^2}$
3	P_1^2	0	$\mathbf{P_1\ P_2}$	$\mathbf{P_1\ P_2}$
4	0	$\mathbf{P_1\ P_2}$	$\mathbf{P_2^2}$	$\mathbf{P_1\ P_2}$

"i" in columns except for those printed in gothic should be $1 \leqq i \leqq (m-a)$, while "i" in columns printed in gothic should be $1 \leqq i \leqq (m-a-1)$.

The probabilities of occurrence of individual at each shallower and deeper hook are represented respectively as $P_1 = \frac{N_1}{2m}$ and $P_2 = \frac{N_2}{2m}$. Represent $k = a(H+1)+R$ in the same manner as shown in the preceding paragraphs, and the hooks spaced by k hook-intervals from respective hooks in the ith basket, the probabilities of occurrence of individual at respective hooks and the probabilities of both of two hooks spaced by k hook-intervals being occupied by individuals are respectively illustrated in Tables 4,5 and 6. Accordingly, the expected numbers of two hooks spaced by k

hook-intervals being occupied by individuals are represented as follows:

at $R=0$ $X(k)=(m-a)(2P_1^2+2P_2^2)$ ..... (9)

$R=1$ $X(k)=(m-a)(2P_1P_2+P_2^2)$ ..... (10)

$R=2$ $X(k)=(m-a)(2P_1P_2+P_1^2)-P_1^2$ ..... (11)

$R=3$ $X(k)=(m-a)(2P_1P_2+P_1^2)-2P_1P_2$ ..... (12)

$R=4$ $X(k)=(m-a-1)(2P_1P_2+P_2^2)$ ..... (13)

The theoretical values, $X_{(k)}$, of this type decrease with the increase of k being distributed in 3 levels.

b) The formulae applicable to the gears with 5 hooks in each basket

Hooks are situated in 3 levels. Here, let us set that N_1, N_2 and N_3 individuals are scattered by chance respectively at the shallower, middle and deeper hooks in a row of gears constituted of m consecutive baskets. The probabilities of occurrence of individual at the shallower, middle and deeper hooks are represented respectively as $P_1=\frac{N_1}{2m}$, $P_2=\frac{N_2}{2m}$ and $P_3=\frac{N_3}{m}$. Then, representing $k=a(H+1)+R$ the hooks spaced by k hook-intervals from respective hooks in the ith basket and the

Table 7. The hooks spaced by k hook-intervals from respective hooks in the ith basket ($H=5$).

R \ h	1	2	3	4	5
0	1	2	3	4	5
1	2	3	4	5	B
2	3	4	5	B	1′
3	4	5	B	1′	2′
4	5	B	1′	2′	3′
5	B	1′	2′	3′	4′

The footnotes in Table 4 are available here, too.

Table 8. Catch rates of respective hooks shown in Table 7 ; the influence of the difference of catch rates due to the different depth levels of respective hooks is taken into consideration ($H=5$).

R \ h	1	2	3	4	5
	P_1	P_2	P_3	P_2	P_1
0	P_1	P_2	P_3	P_2	P_1
1	P_2	P_3	P_2	P_1	0
2	P_3	P_2	P_1	0	P_1
3	P_2	P_1	0	P_1	P_2
4	P_1	0	P_1	P_2	P_3
5	0	P_1	P_2	P_3	P_2

probabilities of occurrence of individual at respective hooks are given in Tables 7 and 8. Accordingly, the formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by individuals, $X_{(k)}$, are represented as follows:

at $R=0$ $X_{(k)}=(m-a)(2P_1^2+2P_2^2+P_3^2)$ ..... (14)

$R=1$ $X_{(k)}=(m-a)(2P_1P_2+2P_2P_3)$ ..... (15)

$R=2$ $X_{(k)}=(m-a)(2P_1P_3+P_2^2+P_1^2)-P_1^2$ ..... (16)

$R=3$ $X_{(k)}=(m-a)(4P_1P_2)-2P_1P_2$ ..... (17)

$R=4$ $X_{(k)}=(m-a)(2P_1P_3+P_2^2+P_1^2)-(2P_1P_3+P_2^2)$ ..... (18)

$R=5$ $X_{(k)}=(m-a-1)(2P_1P_2+2P_2P_3)$ ..... (19)

The theoretical values estimated by these formulae decrease gradually with the increase of k being distributed in 4 levels.

6) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rates increase with the soaking time and they differ according to the depth levels

Next group of formulae are constructed for the purpose of taking the influence of increase of the catch rate with the soaking time and that of the catch rate varying according to the different depth levels of hooks into consideration, when the detailed spatial relation between individuals distributed along a row of gears is examined.

Table 9. Catch rates corresponding to respective columns of Table 4 ; the influence of the gradient of the catch rate and that of the difference of catch rates due to the different depth levels of respective hooks are taken into consideration ($H=4$).

R \ h	1	2	3	4
	$P_1+i\Delta P_1$	$P_2+i\Delta P_2$	$P_2+i\Delta P_2$	$P_1+i\Delta P_1$
0	$P_1+\overline{i+a}\Delta P_1$	$P_2+\overline{i+a}\Delta P_2$	$P_2+i+a\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$
1	$P_2+\overline{i+a}\Delta P_2$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0
2	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$
3	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$
4	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$	$P_2+\overline{i+a+1}\Delta P_2$

To represent the gradient of catch rates of hooks in respective depth groups, P_1, P_2, P_3, ΔP_1, ΔP_2 and ΔP_3 are defined as shown below. When there are 4 hooks in each basket, the catch rate of each shallower hook in the ith basket is represented as $(P_1+i\Delta P_1)$ and that of each deeper hook as $(P_2+i\Delta P_2)$, while when there are 5 hooks in each basket, the catch rate of each shallower hook in the ith basket is represented as $(P_1+i\Delta P_1)$, that of each hook in the middle layer as $(P_2+i\Delta P_2)$ and that of each deeper hook as $(P_3+i\Delta P_3)$; in other words, $N_1=2\sum_{i=1}^{m}(P_1+i\Delta P_1)$ and $N_2=2\sum_{i=1}^{m}(P_2+i\Delta P_2)$ when there are 4 hooks in each basket, while $N_1=2\sum_{i=1}^{m}(P_1+i\Delta P_1)$, $N_2=2\sum_{i=1}^{m}(P_2+i\Delta P_2)$ and $N_3=\sum_{i=1}^{m}(P_3+i\Delta P_3)$ when there are 5 hooks in each basket. Then, in the same way as shown in the conversion of formulae (1)

and (2) into (3) and (4), replaced P_1 and P_2 of the formulae (9)$\sim$(13) or P_1, P_2 and P_3 of the formulae (14)$\sim$(19) into $(P_1+i\Delta P_1)$, $(P_2+i\Delta P_2)$ *etc.* or $(P_1+i\Delta P_1)$, $(P_2+i\Delta P_2)$, $(P_3+i\Delta P_3)$ *etc.*, the formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by individuals, when the gears have 4 or 5 hooks in each basket, are converted as follows:

a) The formulae applicable to the gears having 4 hooks in each basket

R = 0

$$X_{(k)} = 2\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1) + 2\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$= 2\left[P_1^2(m-a)\left\{1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right\}\right.$$

$$\left.+P_2^2(m-a)\left\{1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right\}\right] \quad \cdots\cdots (20)$$

R = 1

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$= P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_2^2(m-a)\left[1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right] \quad \cdots\cdots (21)$$

R = 2

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)$$

$$= P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_1^2(m-a-1)\left[1+(m+1)\delta_1+(m-a)(2m+a+2)\frac{\delta_1^2}{6}\right] \quad \cdots\cdots (22)$$

R = 3

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1) + \sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$$

$$= P_1^2(m-a)\left[1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right]$$

$$+P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right] \quad \cdots\cdots (23)$$

$R=4$

$$X_{(k)}=\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\,\Delta P_1)+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\,\Delta P_2)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\,\Delta P_2)$$

$$=P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_2{}^2(m-a-1)\left[1+(m+1)\delta_2+(m-a)(2m+a+2)\frac{\delta_2{}^2}{6}\right] \quad \cdots\cdots (24)$$

here $\delta_1=\dfrac{\Delta P_1}{P_1}$ and $\delta_2=\dfrac{\Delta P_2}{P_2}$

because

$$\sum_{i=1}^{m-a}(P_{\mathrm{I}}+i\Delta P_{\mathrm{I}})(P_{\mathrm{II}}+\overline{i+a}\Delta P_{\mathrm{II}})=P_{\mathrm{I}}P_{\mathrm{II}}\sum_{i=1}^{m-a}(1+i\delta_{\mathrm{I}})(1+\overline{i+a}\Delta\delta_{\mathrm{II}})$$

$$=P_{\mathrm{I}}P_{\mathrm{II}}\sum_{i=1}^{m-a}\left[(1+a\delta_{\mathrm{II}})+(\delta_{\mathrm{I}}+\delta_{\mathrm{II}}+a\delta_{\mathrm{I}}\delta_{\mathrm{II}})i+\delta_{\mathrm{I}}\delta_{\mathrm{II}}i^2\right]$$

$$=P_{\mathrm{I}}P_{\mathrm{II}}(m-a)\left[1+a\delta_{\mathrm{II}}+\left\{(2m+a+1)\delta_{\mathrm{I}}\delta_{\mathrm{II}}+3(\delta_{\mathrm{I}}+\delta_{\mathrm{II}})\right\}\frac{(m-a+1)}{6}\right]$$

and $$\sum_{i=1}^{m-a-1}(P_{\mathrm{I}}+i\Delta P_{\mathrm{I}})(P_{\mathrm{I}}+\overline{i+a+1}\,\Delta P_{\mathrm{I}})$$

$$=P_{\mathrm{I}}P_{\mathrm{I}}(m-a-1)\left[1+(a+1)\delta_{\mathrm{I}}+\left\{(2m+a+2)\delta_{\mathrm{I}}\delta_{\mathrm{I}}+3(\delta_{\mathrm{I}}+\delta_{\mathrm{I}})\right\}\frac{(m-a)}{6}\right]$$

here $\delta_{\mathrm{I}}=\dfrac{\Delta P_{\mathrm{I}}}{P_{\mathrm{I}}}$ and $\delta_{\mathrm{I}}=\dfrac{\Delta P_{\mathrm{I}}}{P_{\mathrm{I}}}$.

b) The formulae applicable to the gears having 5 hooks in each basket

Table 10. Catch rates corresponding to respective columns of Table 7; the influence of the gradient of the catch rate and that of the difference of catch rates due to the different depth levels of respective hooks are taken into consideration ($H=5$).

R \ h	1	2	3	4	5
	$P_1+i\Delta P_1$	$P_2+i\Delta P_2$	$P_3+i\Delta P_3$	$P_2+i\Delta P_2$	$P_1+i\Delta P_1$
0	$P_1+\overline{i+a}\Delta P_1$	$P_2+\overline{i+a}\Delta P_2$	$P_3+\overline{i+a}\Delta P_3$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$
1	$P_2+\overline{i+a}\Delta P_2$	$P_3+\overline{i+a}\Delta P_3$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0
2	$P_3+\overline{i+a}\Delta P_3$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$
3	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$
4	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$	$P_3+\overline{i+a+1}\Delta P_3$
5	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$	$P_3+\overline{i+a+1}\Delta P_3$	$P_2+\overline{i+a+1}\Delta P_2$

$R=0$

$$X_{(k)}=2\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)+2\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$
$$+\sum_{i=1}^{m-a}(P_3+i\Delta P_3)(P_3+\overline{i+a}\Delta P_3)$$
$$=2P_1^2(m-a)\left[1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right]$$
$$+2P_2^2(m-a)\left[1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right]$$
$$+P_3^2(m-a)\left[1+(m+1)\delta_3+(m-a+1)(2m+a+1)\frac{\delta_3^2}{6}\right]\cdots\cdots(25)$$

$R=1$

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_3+\overline{i+a}\Delta P_3)$$
$$+\sum_{i=1}^{m-a}(P_3+i\Delta P_3)(P_2+\overline{i+a}\Delta P_2)+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$
$$=P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$
$$+P_2P_3(m-a)\left[2+(m+1)(\delta_2+\delta_3)+(m-a+1)(2m+a+1)\frac{\delta_2\delta_3}{3}\right]\cdots\cdots(26)$$

$R=2$

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_3+\overline{i+a}\Delta P_3)+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$
$$+\sum_{i=1}^{m-a}(P_3+i\Delta P_3)(P_1+\overline{i+a}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)$$
$$=P_1P_3(m-a)\left[2+(m+1)(\delta_1+\delta_3)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_3}{3}\right]$$
$$+2P_2^2(m-a)\left[1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right]$$
$$+P_1^2(m-a-1)\left[1+(m+1)\delta_1+(m-a)(2m+a+2)\frac{\delta_1^2}{6}\right]\cdots\cdots(27)$$

$R=3$

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$
$$+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$$
$$=P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right] \quad \cdots\cdots (28)$$

R = 4

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_3+i\Delta P_3)(P_1+\overline{i+a+1}\Delta P_1)$$
$$+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_3+\overline{i+a+1}\Delta P_3)$$
$$=P_1^2(m-a)\left[1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right]$$
$$+P_1P_3(m-a-1)\left[2+(m+1)(\delta_1+\delta_3)+(m-a)(2m+a+2)\frac{\delta_1\delta_3}{3}\right]$$
$$+P_2^2(m-a-1)\left[1+(m+1)\delta_2+(m-a)(2m+a+2)\frac{\delta_2^2}{6}\right] \quad \cdots\cdots (29)$$

R = 5

$$X_{(k)}=\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_3+i\Delta P_3)(P_2+\overline{i+a+1}\Delta P_2)$$
$$+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_3+\overline{i+a+1}\Delta P_3)+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$$
$$=P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right]$$
$$+P_2P_3(m-a-1)\left[2+(m+1)(\delta_2+\delta_3)+(m-a)(2m+a+2)\frac{\delta_2\delta_3}{3}\right] \quad \cdots\cdots (30)$$

here, $\delta_1=\frac{\Delta P_1}{P_1}$, $\delta_2=\frac{\Delta P_2}{P_2}$ and $\delta_3=\frac{\Delta P_3}{P_3}$.

Theoretical values, $X_{(k)}$, of this type estimated at k, not so large, take a little higher values than those estimated by using the formulae (9)~(19), while the outline of variation with the increase of k is quite the same in both cases, although the rate of decrease with the increase of k is slightly sharper in the former than in the latter.

3. Analyses of the distribution pattern projected along the gears

If we analyze the spatial relation by using a very short length as the unit section, we are hardly able to find out the existence of any schools of a considerable size, because the scale of consideration is so short that it might result that even the shortest interval between the adjacent individuals is thought erroneously as consisting of more than one or two sections, individuals are misregarded to be scattered more evenly than by chance despite of the fact actually they consist of contagious schools when they are seen by using some longer units or the access to the clear conclusion

is strongly interfered by the fine structure which may rather be regarded as intra-school (or sub-school) patterns, though we can be acquainted with the more detailed relations between individuals. Consequently, the longer the unit length should be, the more effective to examine the existence of large schools, as the interference of fine structures are removed. Accordingly, it is desirable to adopt longer intervals to clear out the outline of the spatial relation, yet it is desirable, on the other hand, that there are more than 10 sections at the last k in consideration in order to make free from the accidental error in the actual counting in the range of k from O to a considerable length. Nevertheless the total length of a row of gears is limited, although it is long enough, these days, as to need a whole day to soak in the whole of gears and then haul up it again. For these reasons, at first, the width of 5 consecutive baskets is adopted as the unit section; this is approximately 1 km long or 1/75 of total length of a row of gears. However, when the analyses are carried out by using such a long interval as the unit section, the outline of the spatial relation within the length of respective units or thereabout is left unrevealed. Hence another series of examinations is added; here the width of one basket ($\fallingdotseq ca.$ 200 m) is used as the unit section for formulae (1)~(4), instead of 5 consecutive baskets in the preceding series. This is very significant, because the existence of schools or sub-schools of 1, 2 or mostly shorter than 5 units width (= 25 baskets $\fallingdotseq$ 5 km) is detected in most examples by next series of examinations and it is necessary to examine the spatial relation in the shorter range and moreover it is indispensable as an intermediate step for finding out the conclusion common to the distribution patterns of respective examples, uniting the results of the preceding series of analyses pursued to clarify the outline and being significant rather ecologically with those of the following ones which are rather important as a theoretical basis for technical problems. The full scales in the relation diagrams of this series correspond to 10 notches, 1/5 of those of the preceding series, and 10 notches of this series correspond to the full scales of k of the following series. Moreover, the estimated values of this series are approximately 1/5 time those of the preceding series. It seems to be one of the characteristics of this series, that the amplitude of deviation of the observed values from the estimated ones is the largest of all these three series of analyses and this makes it easy to consider upon the spatial relation. And lastly, another series of analyses is tried, in which the unit length is shortened to a single hook-interval ($\fallingdotseq ca.$ 40 m), as this is not only necessary to clarify the elemental structure from the ecological points but also very important from the technical point of view.

Notes for decoding the diagrams and notation used in them

When the observed value at a certain k takes the same value as the estimated one, it is safely considered that the number of individuals occurring in the sections or at the hooks spaced by that k intervals from any occupied section or hook is as much as that being distributed by chance, while when the observed value is higher or lower than the estimated one, respectively more or less numerous individuals should be caught in the sections or at the hooks spaced by k intervals from any occupied

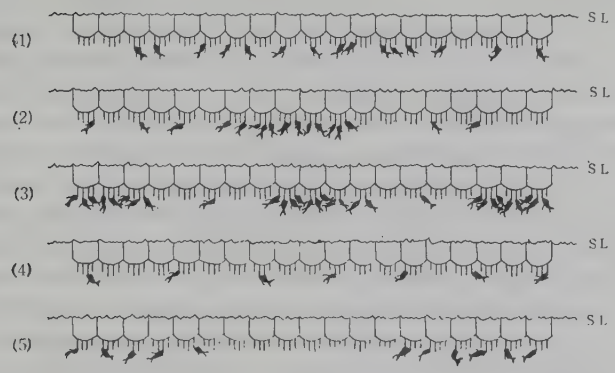


Fig. 6. Schematic representation of the distribution patterns of fishes along the long-line. Notes: S. L.: Sea Level. (1) Random distribution, (2) single contagious school, (3) many contagious schools, (4) single self-spacing school and (5) many self-spacing schools.

section or hook. But when the observed values are always equal to the estimated ones at any values of k, this means simply that the same number of individuals as that distributed by chance are caught in the sections or at the hooks spaced by k intervals from any occupied sections or hooks at any values of k. In this case no explanation is given to the positional relation which may be found in the distribution of the couples of individuals at respective intervals —— whether the couples of individuals at narrower intervals are gathered within several restricted parts along a row or they are distributed by chance. The last case can safely be considered to indicate that the distribution of individuals is quite by chance, because the observed values at k not so large should be higher than the estimated value and it is hardly possible that the observed values are the same as the estimated ones at any value of k if the distribution of the couples of individuals at narrower intervals is restricted. When the observed values in the range from $k=0$ to a certain value ($k=k_1$) are continuously higher than the corresponding estimated ones, it is deducible from this fact only that the couples of individuals spaced by shorter than k_1 occur more frequently than those in the case when they are scattered by chance. But, this gives no explanation to the positional relation between such couples nor that between such and other couples. Anyhow it can be cleared from this whether such narrowly spaced couples are observable within a restricted part or they are quite scattered; —— at least this shows distinctly that the contagiousness reaches k_1 intervals. Accordingly, one of the characteristics of the distribution pattern, perhaps it may be an average width of schools, may be expressed by k_1. If the couples spaced by the interval shorter than k_1 are observable mostly within a single restricted part, no observed value can be higher than the estimated one in the range $k>k_1$. But if they are not gathered within a restricted part, several patches of observed values higher than the estimated ones may occur and evidently these are reflecting another characteristics of the distribution pattern,

perhaps the distribution pattern of such narrowly spaced couples. And the distance between the centers of adjacent patches can be considered as an average interval between schools. Thus, it is presumable whether the population is constituted of a single contagious school or many ones according to the question whether the observed values higher than the estimated ones are restricted within the range $k_1 \geqq k$ or not. Contrary to the above-mentioned pattern, there are some examples, in which the observed values in the range from $k=0$ to $k=k_2$ are continuously lower than the estimated ones; this means simply that less individuals than those being distributed by chance are observable in the sections or at hooks spaced by the interval shorter than k_2 from any occupied sections or hooks. In such examples, the observed values are raised till they exceed the estimated ones and then decrease again to lesser values with the increase of k. For the same reason mentioned above, the individuals in such examples are considered to be spaced one another more evenly than in the case when they are distributed by chance. But when more than one patch of such a pattern is met with along a single row, more than one peak is observable. Such a case can easily be recognized in the statistical treatment, but it seems rather difficult to understand such a case actually, although this can be expected when individuals show any territorial behavior or the length of unit section under the consideration is too short as compared with the distribution pattern of individuals; such a pattern is named as self-spacing, hyponormal or subnormal dispersion (Torii 1953, 1956, Beall 1935, Romell 1930, Blackmann 1935, Ashby 1935 and Grasgow 1939). However, judging from the above-mentioned patterns, it must be noticed that the $X(k)-k$ relation diagram showing quite different contagious pattern can surely be obtained when a enough length is adopted as the unit interval under the consideration.

Besides, there might occur some errors to mistake the width of the overlapping parts for the width of schools when many schools of a considerable width are caught partly overlapping one another, although judging from the fact that the catch rates are actually very low and relatively homogenous the actual existence of such a case is not likely.

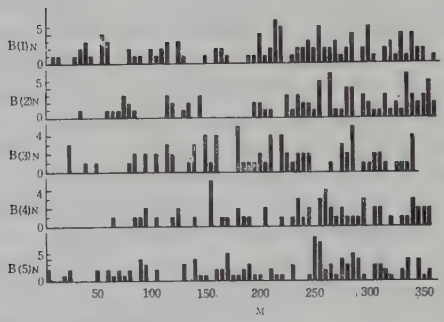
Then, if schools as compact as what are often met with and called as schools in a general sense are caught, the deviation of the observed values may extend from a few ten percents of the estimated ones to the several times of them. In actual cases, however, the deviation of the observed values from the estimated ones is rather small, although the inclination of deviation suggests that the population is composed of many very weakly contagious schools. Accordingly it is safely supposed that tuna is distributed approximately by chance, but its population is composed of many schools of negligibly weak contagiousness when it is examined in detail.

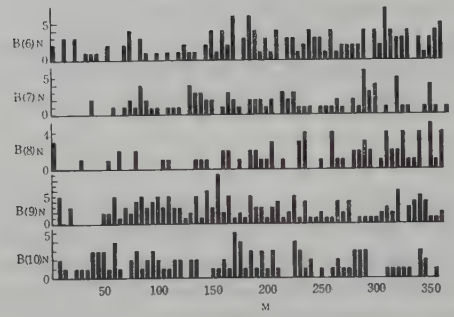
The series of figures noted as (Ⅰ) in Figs. 8, 10 and 12 represent the results of the first series of analyses, in which the width of 5 consecutive baskets (≒*ca.* 1 km) is adopted as the unit length, and the series Ⅱ shows the results of the second one, in which the width of one basket (≒*ca.* 200 m) is adopted as the unit length, while the series Ⅲ illustrates the spatial relation diagrams, in which the unit length

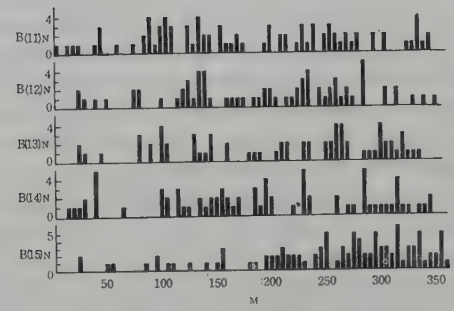
is one hook-interval (≒*ca.* 40 m). In these figures, the estimated values computed by using formulae (1) and (2) (in Series Ⅰ and Ⅱ) or formulae (5) and (6) (in Series Ⅲ), on the supposition that individuals are simply scattered by chance, are represented by empty circles (……○……). While, those represented by black and white circles (------◐------) indicate those estimated by using formulae (3) and (4) (in Series Ⅰ and Ⅱ) or formulae (7) and (8) (in Series Ⅲ) on the supposition that the catch rate increases simply with the soaking time and the chances of respective hooks being occupied by fishes or not are quite independent of one another. Besides, there are two other series of estimated values represented by ◑ and ◒ in Series Ⅲ, the former comprises the values estimated by using formulae (9)～(13) in which simply the influence of the difference of the catch rate of hooks according to the depth levels is taken into consideration while the latter represents the values estimated by using formulae (20)～(24) in which both the above-mentioned influence and that of the increase of the catch rate with the soaking time are taken into consideration. When the values are quite similar between the cases when the above-mentioned influences are taken into consideration or not, or the difference between the values computed under respective conditions is hardly discernible on the diagrams, they are represented by the values calculated under the condition where the above-mentioned influences are not taken into consideration. The distribution pattern of tunas is deduced in the above-mentioned way, by comparing respective series of observed values, indicated by filled circles (—●—), with those estimated theoretically.

1) Big-eye tuna

Generally, the deviation of the observed values in Series Ⅱ from the corresponding ones estimated under the condition where the influence of the gradient of the catch rate is taken into consideration is considerably large, while those in Series Ⅰ and Series Ⅲ from the corresponding values estimated under the condition where the influences of both factors are taken into consideration are nearly negligible. This means that the unit width in the first series, the width of 5 consecutive baskets, is too long to consider upon the existence of the most conspicuous schools, because there occur one or more maxima and minima within 5 consecutive baskets, consequently the apparent distribution assumes falsely uniformity. On the other hand, the unit length adopted in Series Ⅲ, 1 hook-interval, is so short that merely the fine sub-school structures can be cleared out. Besides, it is noticeable that the extremely strong contagiousness is often observed between the adjacent hooks; this fact coincides with the fishermen's saying that big-eye tunas are caught usually in couple and seems to be one of the characteristics of the distribution pattern of big-eye tuna. More detailed examinations of respective examples seem to allude to the following tendencies: ——


B(1)N
B(2)N
B(3)N
B(4)N
B(5)N
50
100
150
200
250
300
350
M


B(6)N
B(7)N
B(8)N
B(9)N
B(10)N
50
100
150
200
250
300
350
M


B(11)N
B(12)N
B(13)N
B(14)N
B(15)N
50
100
150
200
250
300
350
M

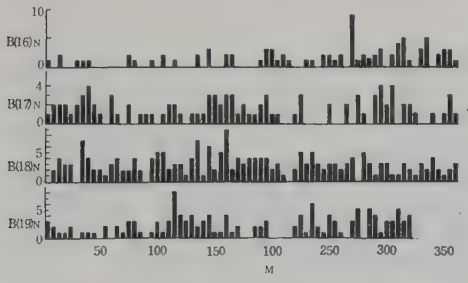


Fig. 7. Distribution of big-eye tuna in each of 5 consecutive baskets in respective examples.
Abbreviations :
M : basket number counted from the initial point of hauling.
N : number of individuals caught by respective consecutive 5 baskets.
B(x) : example of big-eye tuna obtained at the Station "x" in the Fishing Ground No. 1.

Exposition of particular example

Example B 1 : When deducing from the diagram of Series Ⅲ, it becomes clear that the number of individuals caught at the hooks spaced by 6 or less hook-intervals from any occupied hooks is continuously higher than the expected one. Accordingly the elemental structure is considered as the clusters covering 6 hook-intervals (≒250 m), a little longer than the width of 1 basket, although this fact does not mean nothing else than that couples of individuals spaced by shorter than 6 hook-intervals are more frequently met with than theoretically expected. Here, it belongs to other problems whether any individuals are caught or not at hooks inserted between two occupied hooks spaced by shorter than 6 hook-intervals. The diagram of Series Ⅱ shows that most of the elemental clusters cover from 1 to 4 baskets width (≒200～800 m) and are located approximately at every 7 baskets (≒1,500 m). [The expression "nearly at every N hook-intervals (baskets or units)" is hereafter used to indicate that the clusters are observed frequently at N hook-intervals, but it does not mean that exactly every space at N hook-intervals is occupied by fishes, rather, in most cases, some

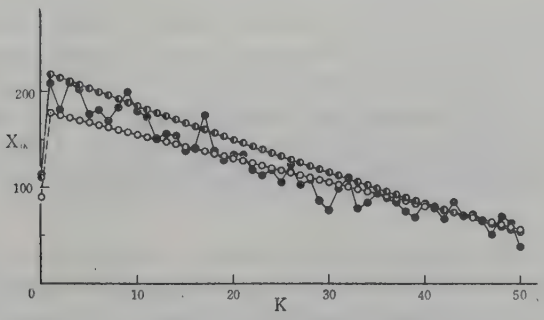


Fig. 8—1 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 1 in the Fishing Ground No. 1).

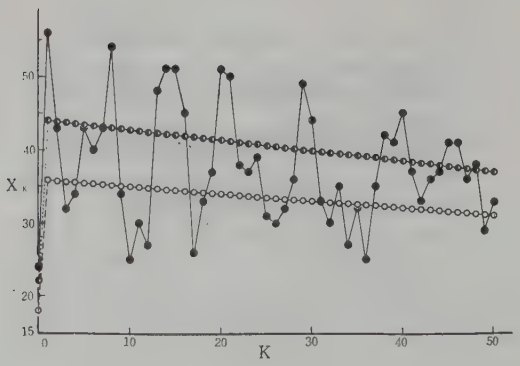


Fig. 8—1 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 1 in the Fishing Ground No. 1).

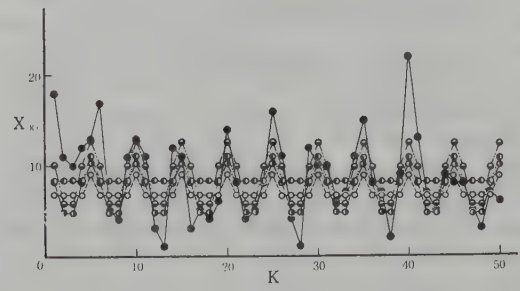


Fig. 8—1 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 1 in the Fishing Ground No. 1)

spaces are left vacant.] Most of the estimated values in Series Ⅰ under the condition that the influence of the gradient of the catch rate is taken into consideration are higher than the observed ones; possibly this is caused by over-estimation of each or both of P_0 and ΔP. The accurate values are considered to be a little lower, perhaps intermediate between the two estimated ones in the diagram. The existence of any distinct large schools is, however, hardly detectable even under the above-mentioned estimated values.

Example B 2 : The deviation of observed values in Series Ⅲ alludes to the existence of the elemental clusters covering a little longer space than 1 basket width (200 m) and spaced by *ca.* 6 or 9 baskets intervals (1~2 km). The same deviation is shown more clearly in Series Ⅱ, although it is reduced into one fifth of that found in Series Ⅲ.

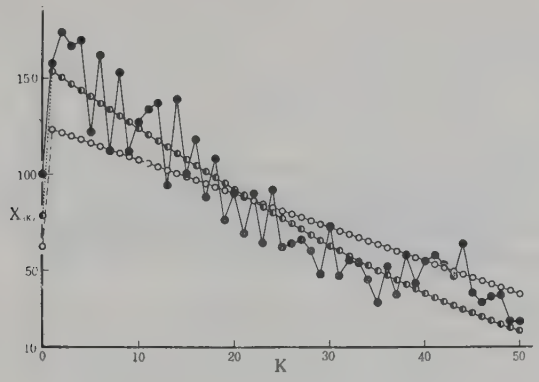


Fig. 8—2 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 2 in the Fishing Ground No. 1).

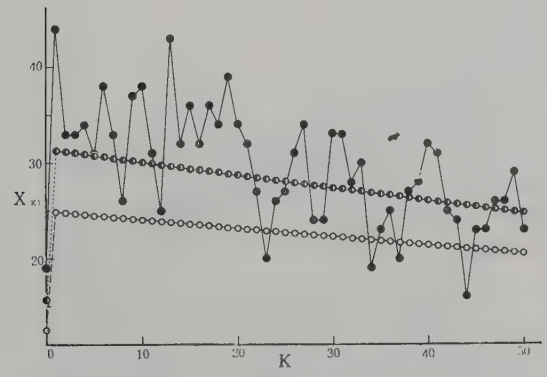


Fig. 8—2 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 2 in the Fishing Ground No. 1).

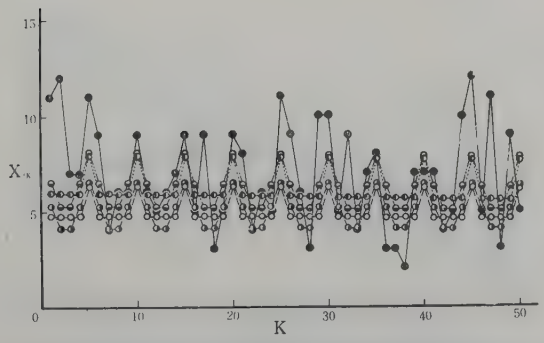


Fig. 8—2 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 2 in the Fishing Ground No. 1).

Besides, it is shown that these elemental clusters or bundles of them further form superior aggregations covering from 2 to 4 baskets width (400～800 m) and spaced by 1 or 2 baskets width (200～400 m). In the diagram of Series Ⅰ, the deviation seems to represent two different periodicities, of which the longer one is of about 40 units (200 baskets width ≒ 40 km) long, while the shorter one is of about 2 units (10 baskets ≒ 2 km) long or thereabout. It is deducible from the above-mentioned facts that the population might be composed of two large schools located at about the 100th and 300th baskets respectively and further they consist of many smaller aggregations of the above-mentioned scale.

Example B 3 : Simultaneous catch at the two adjoining hooks is clearly shown in the diagram of Series Ⅲ. The results of the analysis of the Series Ⅰ show the nearly perfect periodicity of 2 units (2 km). But, when the units are divided into respective

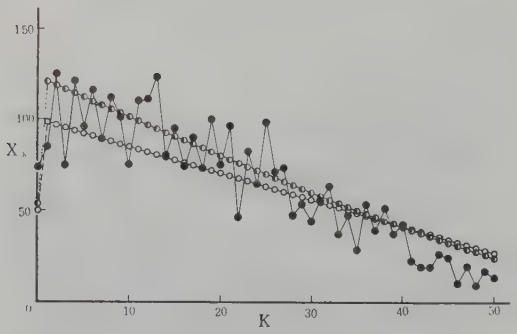


Fig. 8—3 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 3 in the Fishing Ground No. 1).

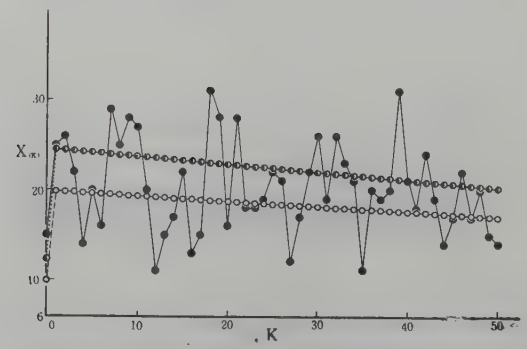


Fig. 8—3 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 3 in the Fishing Ground No. 1).

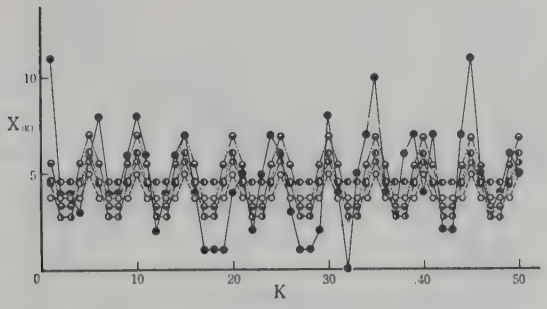


Fig. 8—3 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 3 in the Fishing Ground No. 1).

baskets (results in Series Ⅱ), the periodicity becomes obscure. This is attributable to the fact that the above-mentioned periodicity is a false one caused chiefly by the difference between the length of the unit adopted in Series Ⅰ and the distance between the centers of the adjoining schools and partly by the irregularity of contagiousness of schools. Most probably the real feature of the distribution pattern can be guessed as follows: the elemental clusters of the width shorter than 3 hook-intervals (*ca.* 100 m) (chiefly of the width of 1 hook-interval ≒ *ca.* 40 m) form many aggregations of the higher order covering from 1 to 4 baskets width (200~800 m) and the distribution of these aggregations shows an extremely weak self-spacing or rather the aggregations seem to be distributed by chance.

Example B 4 : The detailed examinations on the diagram of Series Ⅲ reveal that rather conspicuous elemental clusters covering shorter than 4 hook-intervals (*ca.* 150 m) are spaced by from 40 to 50 hook-intervals (1.5~2.0 km) and intervened by some obscure

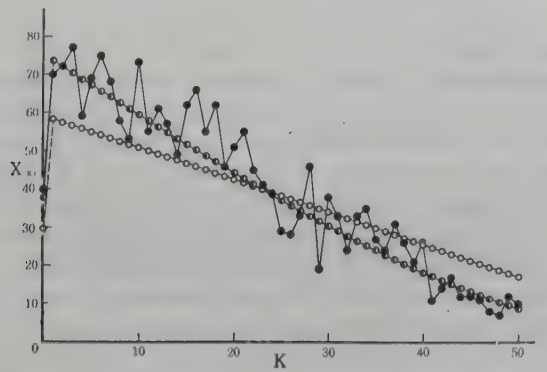


Fig. 8—4 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 4 in the Fishing Ground No. 1).

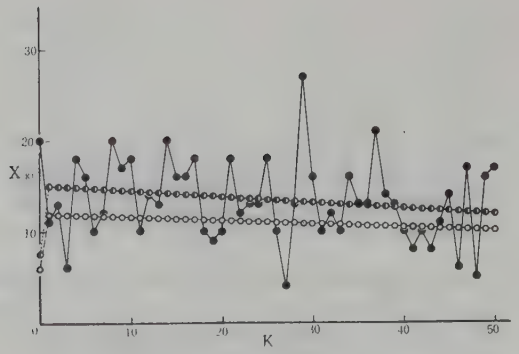


Fig. 8—4 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 1).

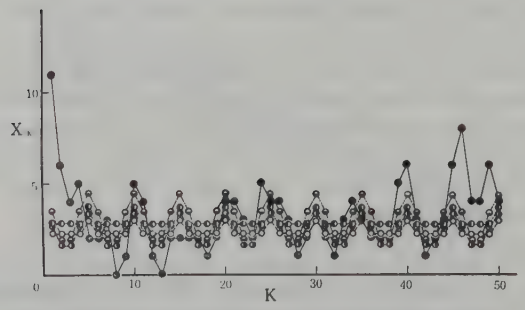


Fig. 8—4 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 4 in the Fishing Ground No. 1).

clusters (contagious degree of these clusters seems to be as high as in the preceding examples, although number of clusters is evidently fewer) at intervals. The diagram of Series Ⅱ suggests the existence of aggregations of 1 to 2 baskets width (200～400 m), of which 2 or 3 are distributed at every 10 baskets (2 km); this seems to indicate the same distribution pattern as that found in Series Ⅲ. The result of the analysis in Series Ⅰ suggests that the periodicity of the deviation of the observed values is irregular. Throughout the examinations on Series Ⅰ～Ⅲ, the distribution pattern of this example may be regarded as follows: the population seems to be constituted of many conspicuous elemental clusters covering the space shorter than 4 hook-intervals (*ca.* 150 m), spaced by *ca.* 5 baskets (1 km) and being accompanied with a few obscure clusters.

Example B 5 : The higher observed values in the range from $k = 0$ to 13 hook-

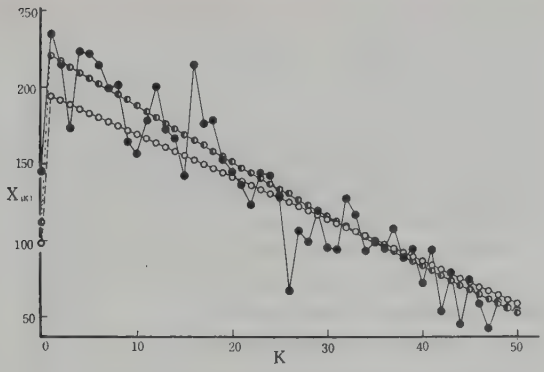


Fig. 8—5 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 5 in the Fishing Ground No. 1).

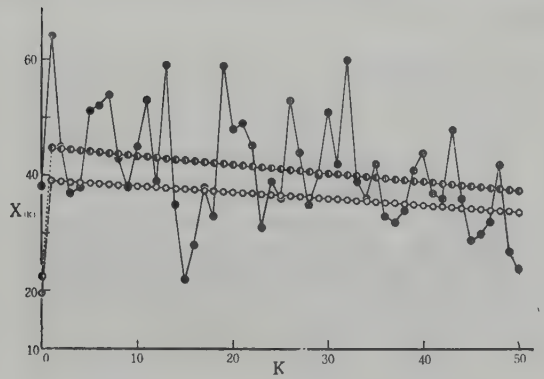


Fig. 8—5 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 5 in the Fishing Ground No. 1).

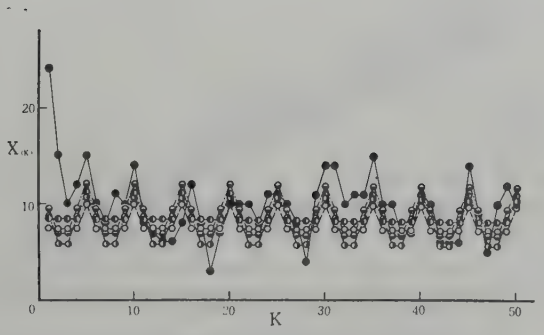


Fig. 8—5 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 5 in the Fishing Ground No. 1).

intervals in Series Ⅲ correspond to those in the range from $k = 0$ to 2 baskets in Series Ⅱ. The next group of higher values in the range from $k = 29$ to 38 hook-intervals in Series Ⅲ is corresponding to those in the range from $k = 5$ to 8 in Series Ⅱ. While the higher values in the range from $k = 0$ to 13 baskets in Series Ⅱ correspond to those in the range from $k = 0$ to 2 in the diagram of Series Ⅰ, the following lower observed values in the range from $k = 14$ to 18 baskets correspond to that at $k = 3$ in Series Ⅰ, and again higher ones in the range from $k = 19$ to 35 or 40 baskets are corresponding to those in the range from $k = 4$ to 8 units in Series Ⅰ. It is deducible from these facts and diagrams that the population is constituted chiefly of many elemental clusters covering 2 baskets (400 m) and spaced by about 3 baskets (600 m). The words "elemental cluster" might easily be accepted, especially in such long clusters as in the case under consideration as being constituted of many individuals, but, actually, they consist mostly of couples of individuals spaced by shorter than a certain width, although isolated individuals may be included in them in some cases. However, the distribution pattern and the density considered altogether, they can be regarded as clusters.

Example B 6 : From the diagram of Series Ⅲ, it is recognizable that the contagiousness is extremely high at the adjoining hooks (40 m) and also a little higher at 5 successive ones (200 m). The continuously higher observed values are found around $k = 10, 30$ and 45 hook-intervals (400 m, *ca.* 1.5 km and *ca.* 2 km), consequently the width of such continuously higher values is estimated respectively as 6, 3, 11 and 8 hook-intervals which correspond to the length from 1 to 3 baskets. The diagram of Series Ⅱ shows the above-mentioned structure more clearly. The diagram of Series Ⅰ indicates that the population is constituted of loosely formed schools covering *ca.* 35 units (≒175 baskets≒35 km), the contagiousness of which is nearly negligible. These schools are then subdivided into many subordinate schools of 1 unit width (1 km)

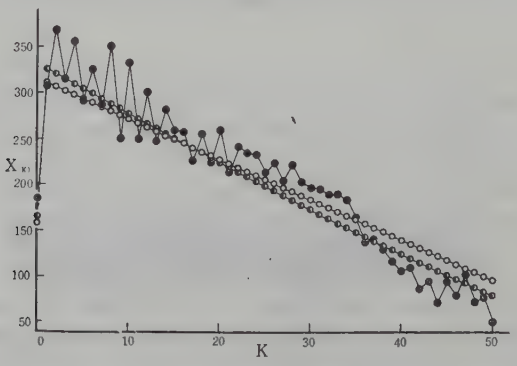


Fig. 8—6 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 6 in the Fishing Ground No. 1).

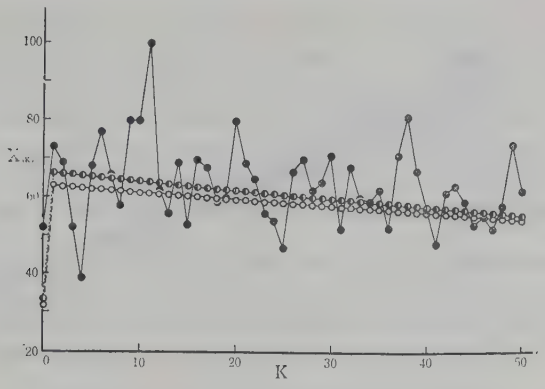


Fig. 8—6 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 6 in the Fishing Ground No. 1).

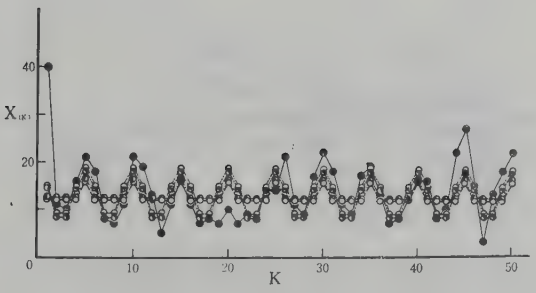


Fig. 8—6 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 6 in the Fishing Ground No. 1).

distributed approximately at every one unit. When the above-mentioned structure is considered together with the results of close examination on the diagram of Series Ⅱ, it becomes clear that the emergence of the subordinate structure is caused by the following mechanism: ——when a row of population consisting of many clusters of 1 to 3 baskets width (200~600 m), distributed each 3 in every 10 baskets (2 km), is divided into sections of 5 consecutive baskets width (1 km), some sections may contain a couple or a single of large clusters, while others may include only a single small one. Thus, the above-mentioned data summarized, the distribution pattern of this example may be safely considered as follows: many elemental clusters of the width from 3 to 10 hook-intervals (100~400 m) are distributed rather uniformly within 175 baskets (35 km) and form as a whole a large school which occupies the principal part of the total catch.

Example B 7 : On the diagram of Series Ⅲ, the width of elemental clusters can be

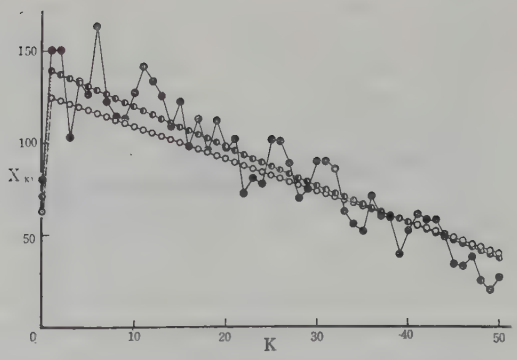


Fig. 8—7 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 7 in the Fishing Ground No. 1).

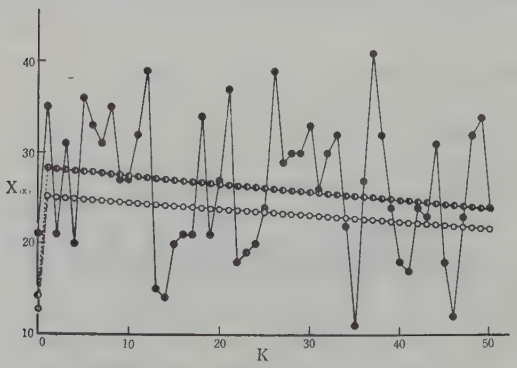


Fig. 8—7 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 7 in the Fishing Ground No. 1).

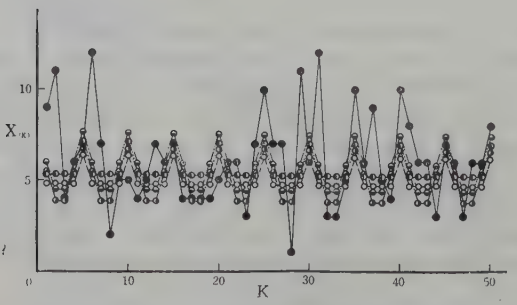


Fig. 8—7 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 7 in the Fishing Ground No. 1).

guessed as 3～7 hook-intervals (100～300 m), when the small deviations of the observed values, which can be regarded as accidental errors, are excluded. The diagram of Series Ⅱ indicates that the elemental clusters detected in Series Ⅲ are further bundled into a number of aggregations of superior order covering 1,2 or rarely 3 baskets width (200, 400 or 600 m), besides the general tendency of deviation quite the same as that represented in Series Ⅰ. The diagram of Series Ⅰ suggests that the above-mentioned aggregations are further bundled into schools of somewhat irregular width.

Example B 8 : The diagram of Series Ⅲ suggests that the contagious degree is extremely high between the adjoining hooks and the size of the elemental clusters is estimated as 2～6 hook-intervals width (80～250 m). The diagram of Series Ⅱ shows that

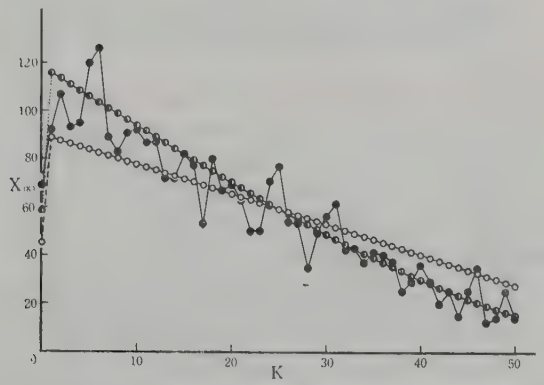


Fig. 8—8 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 8 in the Fishing Ground No. 1).

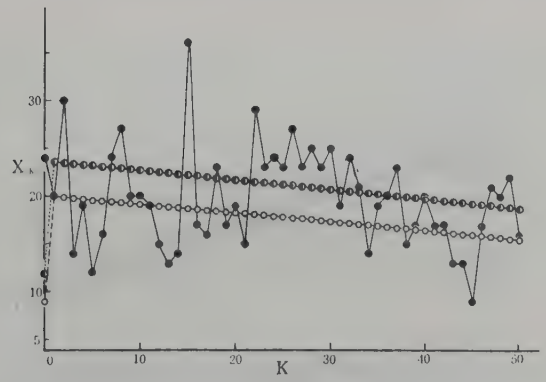


Fig. 8—8 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 8 in the Fishing Ground No. 1).

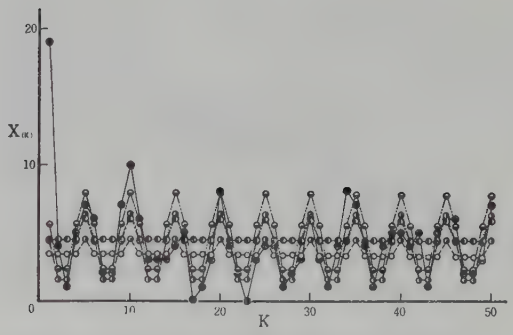


Fig. 8—8 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 8 in the Fishing Ground No. 1).

these elemental clusters, mostly couples of individuals caught at the adjoining hooks, and solitary individuals are further bundled into many aggregations of superior order covering 1 or 2 baskets width (200～400 m) and spaced by 1 or 2 baskets. And the diagram of Series Ⅰ indicates that the population is chiefly constituted of such relatively conspicuous bundles covering 1 or 2 units width (1～2 km) and being evenly distributed throughout a whole row of gears.

Example B 9 : The deviation of the observed values from the estimated ones is very small in all 3 series and this indicates that the distribution is almost by chance. But, the closer examination reveals that the diagram of Series Ⅲ shows that most elemental clusters are couples of individuals hooked side by side (spaced by 40 m) or those leaving a vacant hook between them (spaced by 80 m) and they are observable more frequently at the hooks spaced by 15, 30, 35 or from 45 to 50 hook-intervals (600, 1,200, 1,400, 1,800

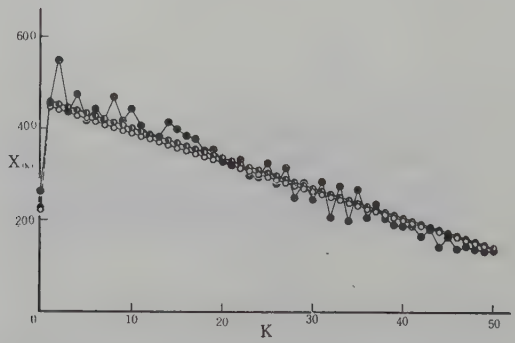


Fig. 8—9 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 9 in the Fishing Ground No. 1).

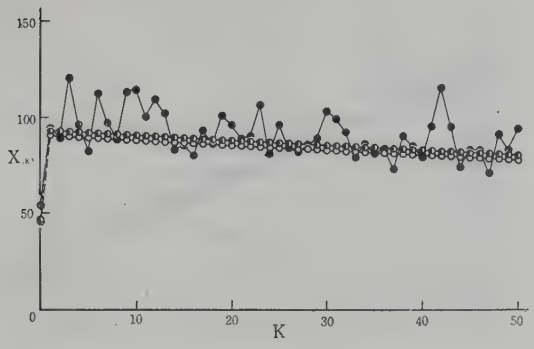


Fig. 8—9 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 9 in the Fishing Ground No. 1).

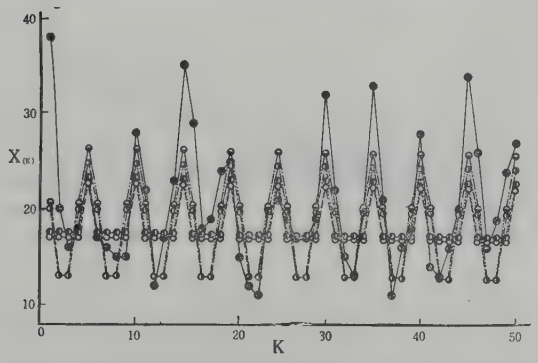


Fig. 8—9 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 9 in the Fishing Ground No. 1).

and 2,000 m) than at others. The diagram of Series Ⅰ alludes to the existence of large schools of negligibly weak contagiousness covering 20 units (20 km) and located around the 100th, 150th and 350th baskets; they are then consisting of many schools of lower order of the width covering 1 or 3 units (1～3 km) and located approximately at every one unit. And the diagram of Series Ⅱ suggests that the subordinate schools found in Series Ⅰ and covering 1 unit (1 km) are, exactly speaking constituted of a single bundle of elemental clusters covering 3 baskets (*ca.* 500 m) or of 2 bundles covering 1 basket (200 m), while the schools covering 3 units (3 km) seem to consist of several bundles covering from 1 to 3 baskets (200～*ca.* 500 m), although the contagious degree is extremely low in both kind of schools.

Example B 10 : The diagram of Series Ⅲ suggests that the finest structure of the population consists of many couples of individuals caught at the adjoining hooks (spaced by 40 m) and the diagram of Series Ⅱ suggests that the above-mentioned elemental

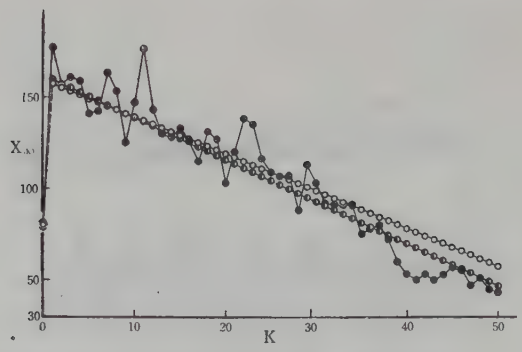


Fig. 8—10 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 10 in the Fishing Ground No. 1).

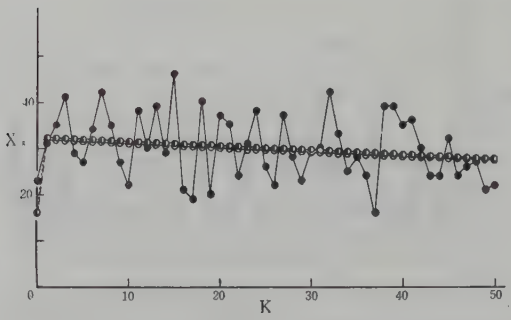


Fig. 8—10 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 10 in the Fishing Ground No. 1).

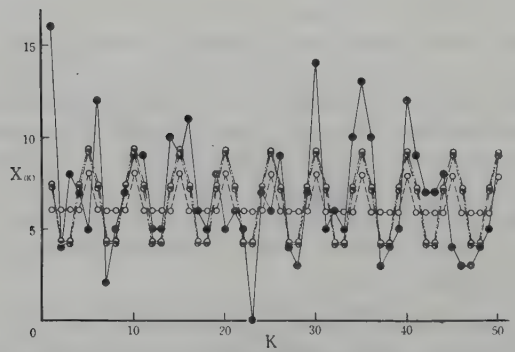


Fig. 8—10 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 10 in the Fishing Ground No. 1).

clusters are bundled into a number of aggregations of higher order covering from 1 to 4 baskets (200~800 m). It is clarified from the diagram of Series Ⅰ that such aggregations are distributed irregularly and further form schools covering from 1 to 4 units (1~4 km), the smaller ones of which are constituted of a single aggregation or elemental cluster while the larger ones represent bundles of aggregations.

Example B 11 : Most of the elemental clusters are small but the contagiousness is rather strong, this indicates that the clusters consist of couples of individuals caught side by side at the adjoining hooks (spaced by 40 m). And the diagram of Series Ⅱ suggests that most of these elemental clusters are bundled into aggregations covering from 2 to 4 baskets (400~800 m). Although the negligibly weak contagiousness extending to the width of *ca.* 30 units (30 km) is observable and this seems to indicate

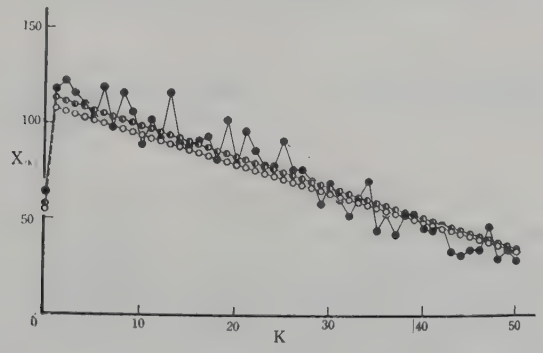


Fig. 8—11 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 11 in the Fishing Ground No. 1).

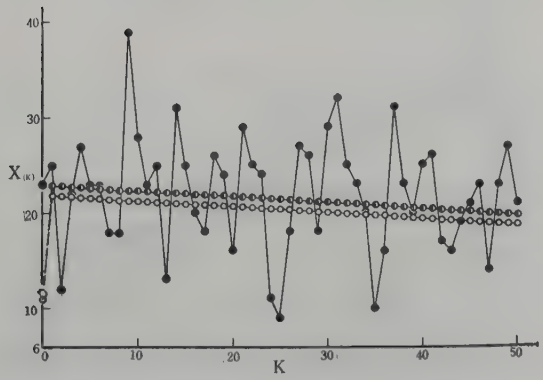


Fig. 8—11 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 11 in the Fishing Ground No. 1).

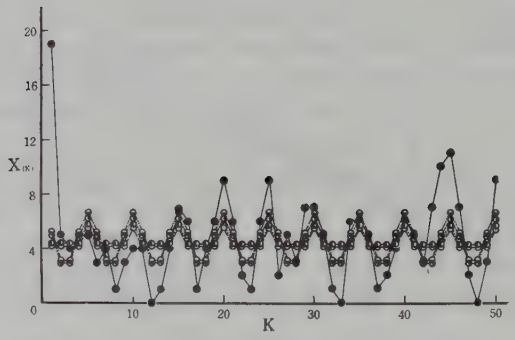


Fig. 8—11 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 11 in the Fishing Ground No. 1).

the existence of large schools located at the spaces from the 75th to the 180th basket and from the 200th to the 350th basket respectively, the structure of subordinate schools covering from 1 to 5 units (1～5 km) is much more conspicuous than the larger ones.

Example B 12 : Deviations of the observed values from the estimated ones are much larger in all 3 series of the present example than in the preceding two examples; this indicates that the schooling tendency is strong in this example. As the density of hooked individuals is low and the distribution is not quite homogenous, in treating the results of analysis of Series Ⅲ not only the couples of individuals caught side by side at the adjoining hooks (spaced by 40 m) but also even the couples of individuals caught at the hooks spaced by *ca.* 2 baskets width (400 m) can be regarded to show some

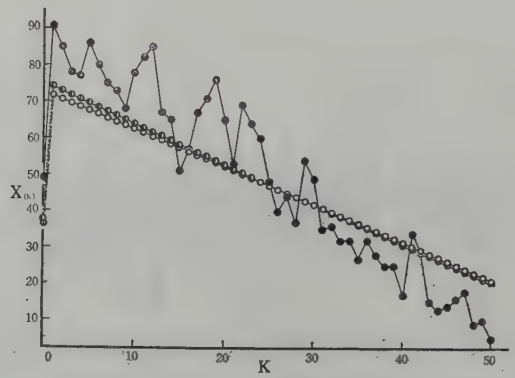


Fig. 8—12 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 12 in the Fishing Ground No. 1).

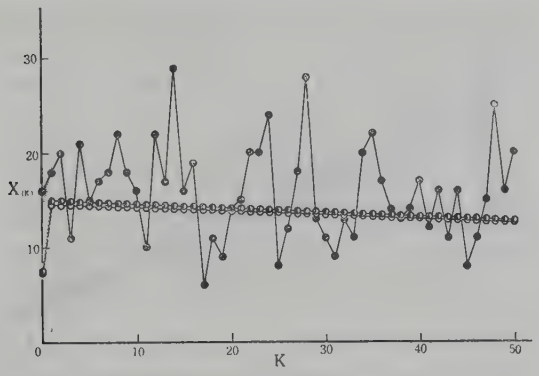


Fig. 8—12 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 12 in the Fishing Ground No. 1).

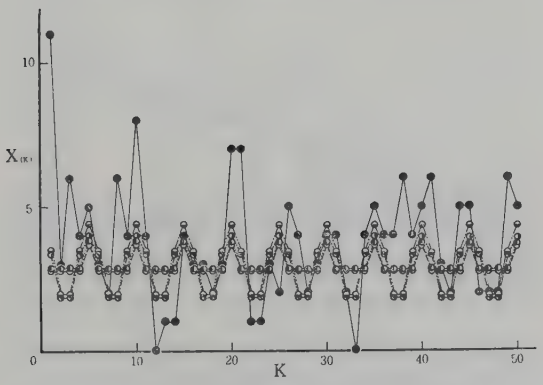


Fig. 8—12 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 12 in the Fishing Ground No. 1).

contagiousness rather than they are regarded as being distributed by chance. Thus they are recognized as elemental clusters. Although the deviation of the observed values from the estimated ones is somewhat conspicuous, no further fact other than those detected in Series Ⅲ and the formation of small bundles can be certified on the diagram of Series Ⅱ. However, the diagram of Series Ⅰ suggests that such elemental clusters and bundles of them further form a school covering the space of *ca.* 30 units (30 km), which corresponds to the part of the higher catch rate, from the 110th to the 260th basket. This school is then subdivided into 6 subordinate schools of 3 or 4 units width (3~4 km), which seem to represent the aggregations located around the 120th, 135th, 165th, 200th, 230th and 250th baskets, respectively.

Example B 13 : On the diagram of Series Ⅲ, it is discerned that elemental clusters of the population in this example consist mostly of couples of individuals caught side

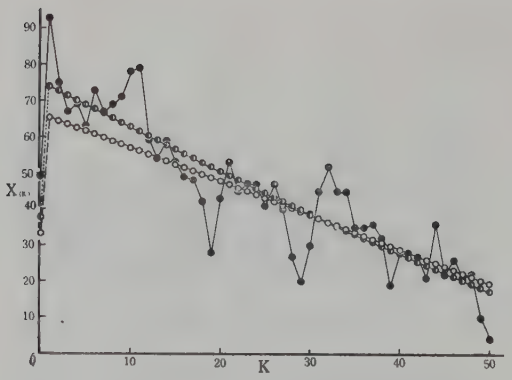


Fig. 8--13 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 13 in the Fishing Ground No. 1).

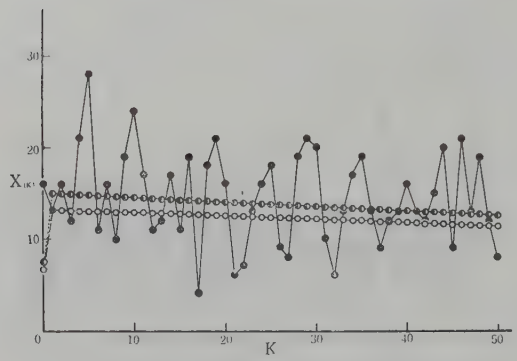


Fig. 8—13 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 13 in the Fishing Ground No. 1).

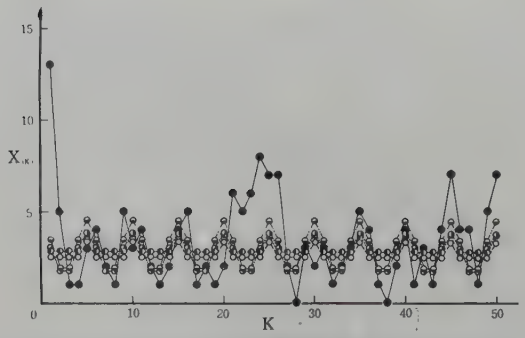


Fig. 8—13 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 13 in the Fishing Ground No. 1).

by side (spaced by 40 m) and partly of couples of individuals caught at hooks being spaced by a hook (spaced by 80 m). And the diagram of Series Ⅱ may add that elemental clusters themselves or small bundles of them form the aggregations of superior order covering from 1 to 3 baskets (200~*ca.* 500 m), when they are seen on a longer scale of 1 basket (200 m). Then the diagram of Series Ⅰ seems to show that the above-mentioned aggregations are apt to form wide loose schools.

Example B 14 : The diagram of Series Ⅲ shows that, besides many couples of individuals caught by adjoining hooks (spaced by 40 m), some couples of individuals caught by the hooks being spaced by 1 (200 m) or occasionally up to 3 or 6 baskets (500 m~1 km) are detected; these may be included in the elemental clusters when they are seen on the standpoint of the distribution as a whole. The diagram of Series Ⅱ suggests the existence of loose bundles of elemental clusters, the detailed feature of which may be

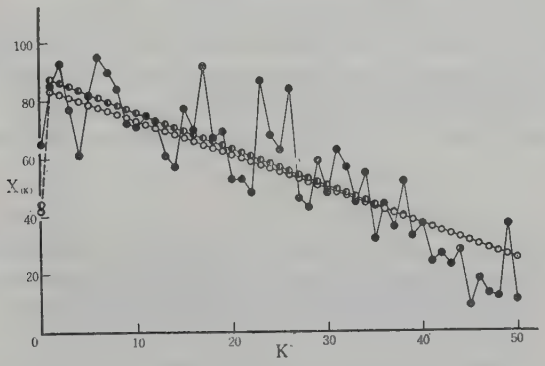


Fig. 8—14 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 14 in the Fishing Ground No. 1).

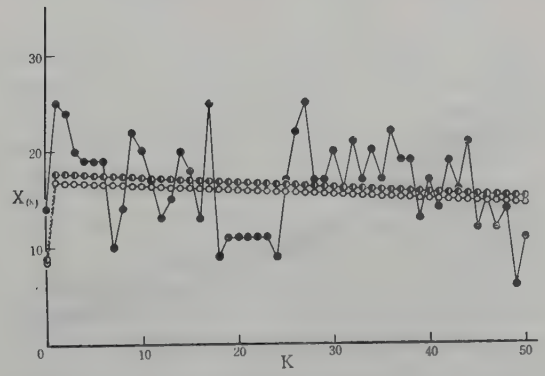


Fig. 8—14 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 14 in the Fishing Ground No. 1).

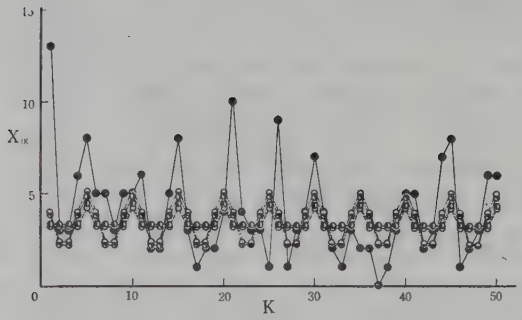


Fig. 8—14 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 14 in the Fishing Ground No. 1).

shown more clearly in Series Ⅰ. The diagram of Series Ⅰ does not show the possibility of the existence of any schools of a considerable width other than several schools covering about 5 units (5 km), which are considered to be located at the range from the 15th to the 40th, around the 150th, 200th and 300th and perhaps also around the 180th baskets.

Example B 15 : The diagram of Series Ⅲ indicates that the elemental clusters are mostly found as couples of individuals hooked side by side (spaced by 40 m) and that a few wider ones are observable being mingled with them. The diagram of Series Ⅱ hardly adds any facts other than that represented in Series Ⅲ. When we compare the observed values with the estimated ones in which the influence of gradient of catch rates is put out of consideration, the diagram of Series Ⅰ may seem to allude to the existence of a single wide and strongly contagious school, but, actually, this is nothing but a phenomenon caused by the strong gradient of distribution. Contrarily when the

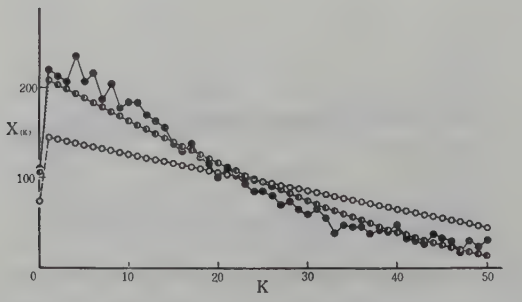


Fig. 8—15 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 15 in the Fishing Ground No. 1).

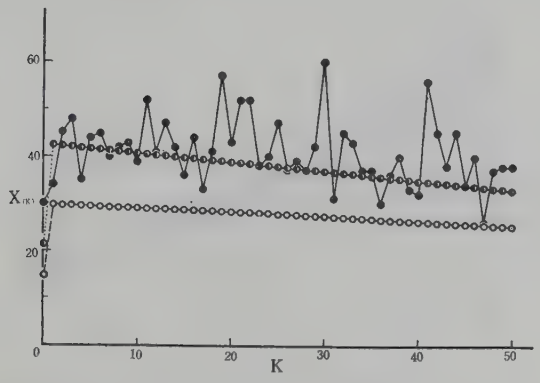


Fig. 8—15 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 15 in the Fishing Ground No. 1).

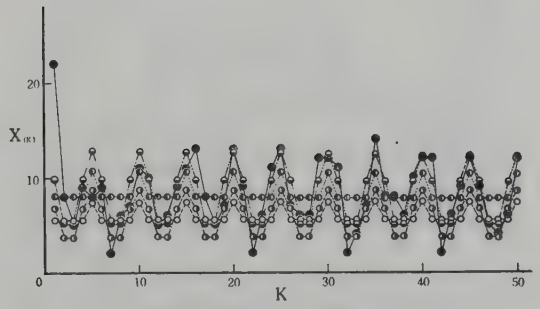


Fig. 8—15 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 15 in the Fishing Ground No. 1).

observed values are compared with the estimated values in which the influence is taken into consideration, the existence of weak but rather conspicuous schools covering each 15 units (15 km) may be suggested; and these are supposed to be located respectively around the 200th and 300th baskets, when the gradient of the distribution is considered together.

Example B 16 : The elemental structure of the population deduced from the diagram of Series Ⅲ consists of the individuals hooked side by side (spaced by 40 m) or those caught at the hooks being spaced by from 1 to 3 baskets (200～500 m), which are also represented as peaks in the diagram of Series Ⅱ. And also this diagram alludes to the formation of loose bundles of these elemental clusters, which is shown more clearly in Series Ⅰ. The diagram of Series Ⅰ suggests that the above-mentioned loose bundles of elemental clusters covering from 1 to 3 units (1～3 km) show the trends to form

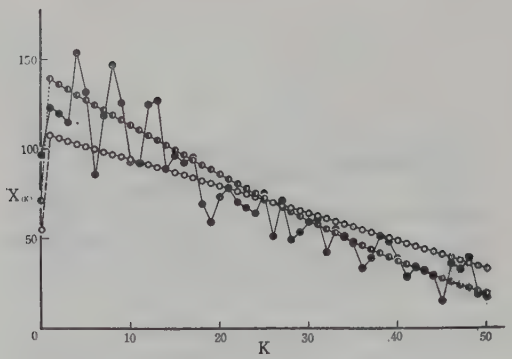


Fig. 8—16 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 16 in the Fishing Ground No. 1).

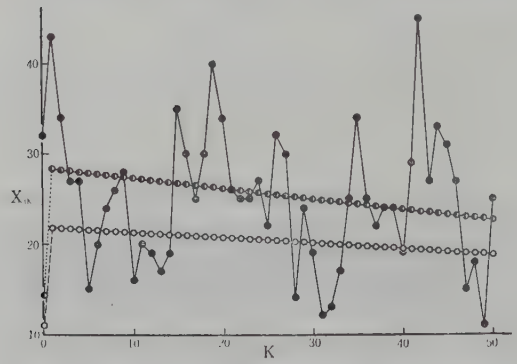


Fig. 8—16 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 16 in the Fishing Ground No. 1).

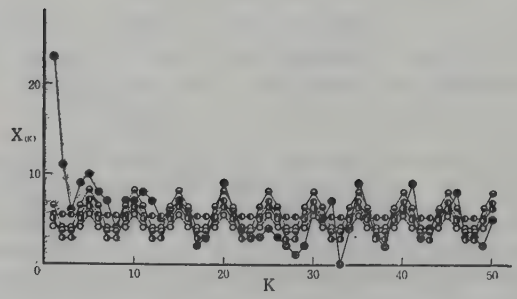


Fig. 8—16 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 16 in the Fishing Ground No. 1).

further a school covering 15 units (15 km), which is, however, so loose that the distribution of bundles within the school may be regarded as self-spacing.

Example B 17 : The examination on the diagram of Series Ⅲ reveals that the couples of individuals caught side by side (spaced by 40 m) and those caught at the hooks spaced by 1 basket (200 m) or thereabout are the principal components of the elemental structure. The spatial relation diagrams of Series Ⅰ and Ⅲ suggest that the population is composed of large schools having the width of 7 units (7 km) or longer and being separated by the distance of approximately 25 units (25 km) between the centers of adjoining schools. These schools are considered to be located around the 25th and 150th baskets and perhaps the part around the 300th basket where the higher catch rate was observed may be regarded as one of such schools; further it is shown that they consist of many subordinate aggregations covering 4-unit width (4 km), which

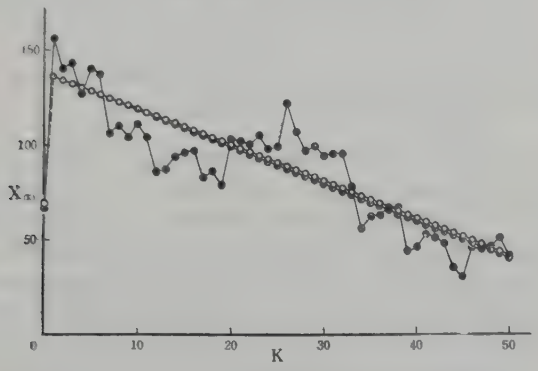


Fig. 8—17 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 17 in the Fishing Ground No. 1).

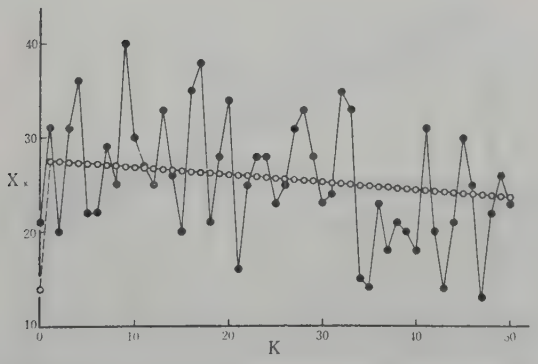


Fig. 8—17 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 17 in the Fishing Ground No. 1).

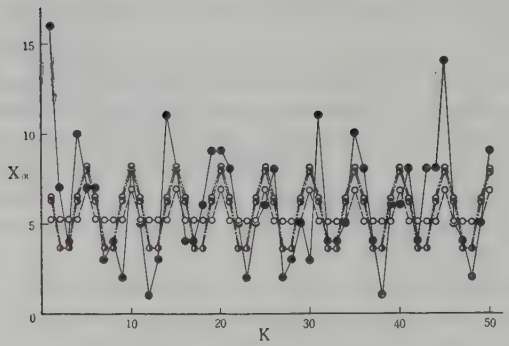


Fig. 8—17 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 17 in the Fishing Ground No. 1).

are considered, then, respectively as a single cluster covering 1 or 2 baskets (200～400 m) or bundles of the above-mentioned elemental clusters.

Example B 18 : The relation diagrams indicate rather clearly that the population contains a large school covering *ca.* 30 units (30 km), which seems to be located around the 150th basket. Then, this school can be subdivided into many subordinate schools of 1- or 2-unit width (1～2 km). And further they are composed of many aggregations covering from 1 to 3 baskets (200～500 m), which are, then, regarded respectively as a single elemental cluster or a bundle of them. The elemental clusters in this example consist of the couples of individuals caught side by side (spaced by 40 m), those caught at the hooks spaced by one hook (80 m) and occasionally some single individuals.

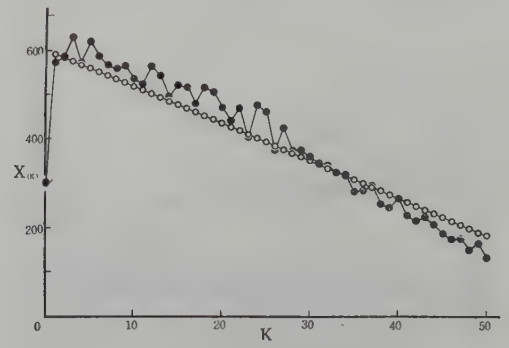


Fig. 8—18(Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 18 in the Fishing Ground No. 1).

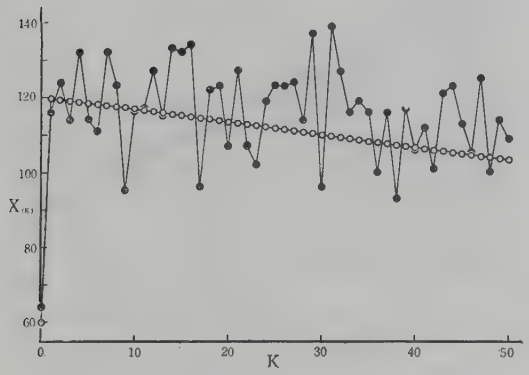


Fig. 8—18 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 18 in the Fishing Ground No. 1).

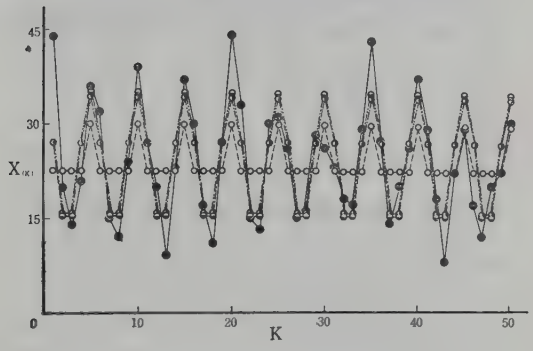


Fig. 8—18 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 18 in the Fishing Ground No. 1).

Example B 19 : The elemental clusters in this example are a little wider than those in other examples, reaching a little beyond 1 basket (200 m) in width. The principal part of catches consists of 3 or more large schools covering 5 units (5 km) or longer and being separated by the distance of *ca.* 25 or 35 units (25~35 km) between the centers of the adjoining schools; and they are located around the 130th, 250th and 300th baskets. These schools seem, then, to be constituted of many elemental clusters or bundles of them.

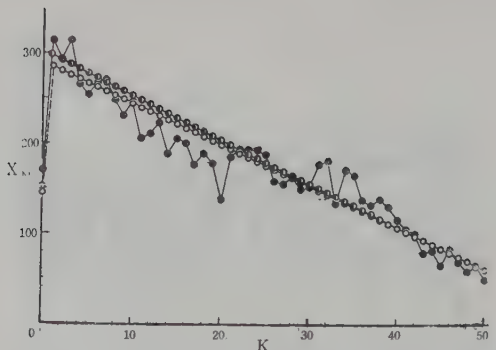


Fig. 8—19 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 19 in the Fishing Ground No. 1).

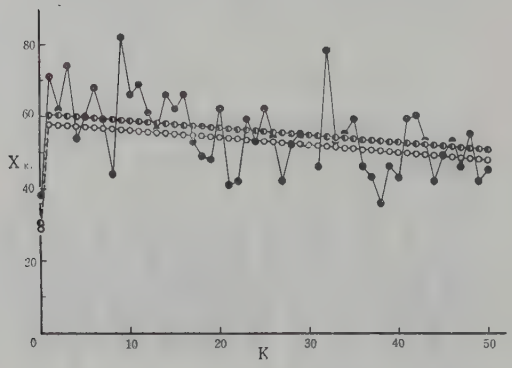


Fig. 8—19 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 19 in the Fishing Ground No. 1).

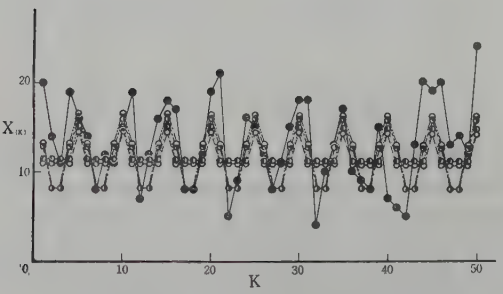


Fig. 8—19 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 19 in the Fishing Ground No. 1).

2) Yellow-fin tuna

The observed actual values and computed ones about yellow-fin tuna are shown in Figs. 10—1 ~10—10. In these figures, however, are included some figures in which it seems unnecessary to compute the values being taken the influence of gradient of the catch rate into consideration, because the gradient is not so prominent, consequently the difference between both series of estimated values, the influence of gradient of the catch rate is taken into consideration or not, is not so large. It may safely be concluded that the yellow-fin tuna is distributed roughly by chance, but exactly speaking, the population is composed of many contagious schools of negligible weakness. And it may be regarded as one of the characteristics of the distribution pattern of the yellow-fin tuna that the width of elemental clusters is remarkable.

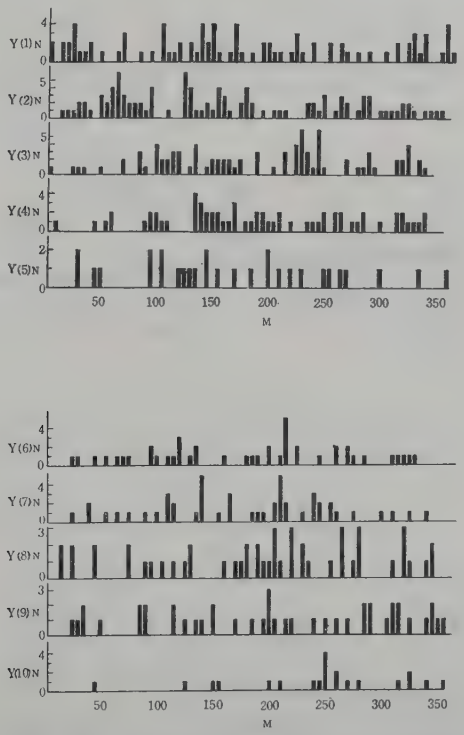


Fig. 9. Distribution of yellow-fin tuna in each of 5 consecutive baskets in respective examples.
Abbreviations :
M : basket number counted from the initial point of hauling.
N : number of individuals caught by respective consecutive 5 baskets.
Y(x) : example of yellow-fin tuna obtained at the Station "x" in the Fishing Ground No. 1.

Exposition of particular example

Example Y 1 : Most of the predominent elemental clusters are the couples of indi-

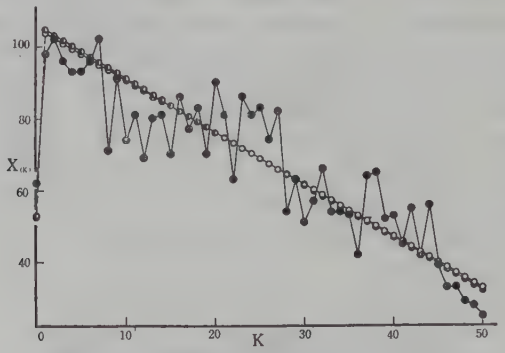


Fig. 10—1 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 1 in the Fishing Ground No. 1).

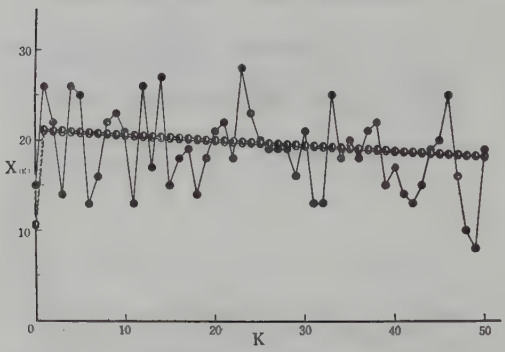


Fig. 10—1 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 1 in the Fishing Ground No. 1).

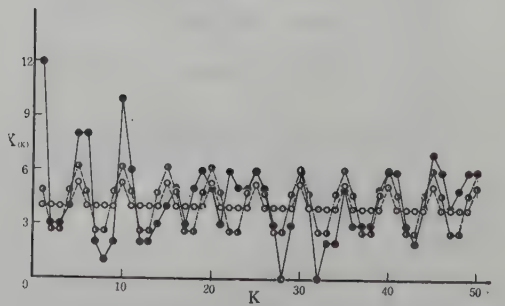


Fig. 10—1 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 1 in the Fishing Ground No. 1).

viduals caught by the adjoining hooks (spaced by 40 m), although the existence of a certain number of couples of individuals spaced by 1 or 2 baskets (200~400 m) must be noticed. And the loose bundles of these clusters, including couples spaced widely, are scattered at self-spacing so weakly that their distribution looks nearly by chance.

Example Y 2 : A considerably long and rather strong contagiousness of the distribution is suggested in the diagram of Series Ⅲ. This diagram shows that the elemental clusters are elongated widely and many of them cover the width of 1 basket (200 m) or sometimes up to 3 baskets (*ca.* 500 m). The loose bundles of from 3 to 5 rather conspicuous aggregations, each of which is perhaps a single elemental cluster, form further small but conspicuous schools, the existence of which is shown more clearly in the diagram of Series Ⅰ and the width of which is about 2 units (2 km) or longer. Such schools are then distributed roughly two in every 10 units (10 km).

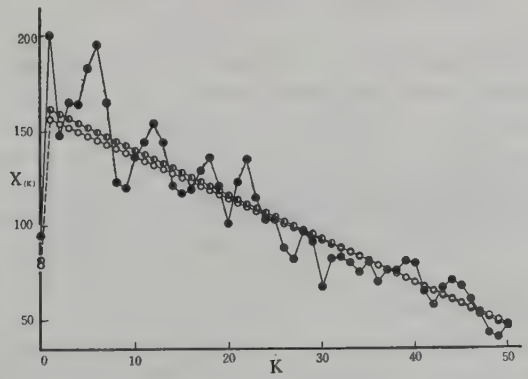


Fig. 10—2 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 2 in the Fishing Ground No. 1).

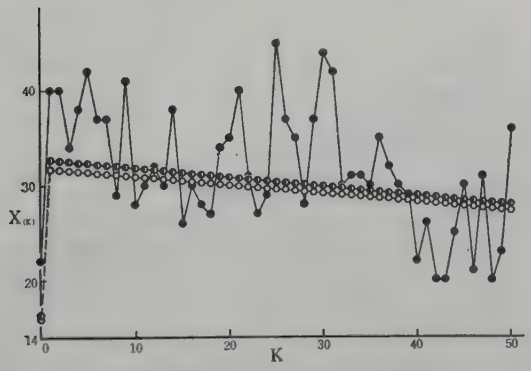


Fig. 10—2 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 2 in the Fishing Ground No. 1).

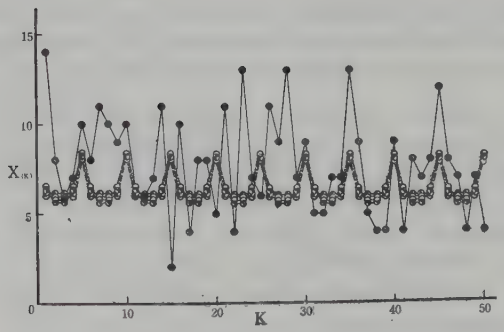


Fig. 10—2 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 2 in the Fishing Ground No. 1).

Example Y 3 : Continuously high values observed in the diagram of Series Ⅲ indicate that most of elemental clusters are diverse couples of individuals spaced by the distance from $k=1$ to 5 (40～200 m). The successively high values observed in this diagram extending in the range from $k=1$ to 20, when several discontinuous low values are disregarded, are corresponding to bundles of high values extending in the range from $k=0$ to 6 in the diagram of Series Ⅱ and bundles of high values covering the width extending from $k=0$ to 25 in the diagram of Series Ⅱ are represented in the diagram of Series Ⅰ by high values found intermittently; and on these the conspicuous structure of the highest order is thought to be the schools covering 1 or 2 units (1～2 km) and being observable at every 2 or 3 units (2～3 km). Besides, this diagram suggests the existence of loosely aggregated schools of a considerable width being spaced by *ca.* 20 units (20 km) and probably corresponding to the parts showing higher catch rates

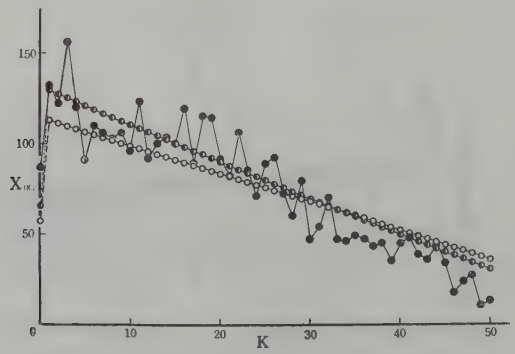


Fig. 10—3 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 3 in the Fishing Ground No. 1).

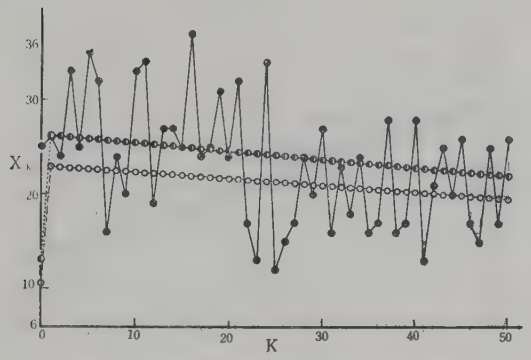


Fig. 10—3 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 3 in the Fishing Ground No. 1).

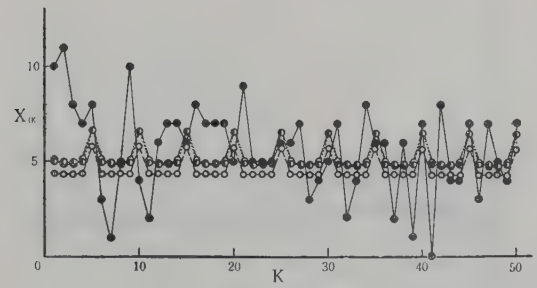


Fig. 10—3 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 3 in the Fishing Ground No. 1).

around the 150th, 250th and 350th baskets, although this superior structure is rather obscure. Concerning the part of higher catch rates around the 100th basket, however, no significant explanation is given by any of diagrams.

Example Y 4 : Though the smallness of the total catch increases the possibility of the accidental errors being introduced, the diagram of Series Ⅲ seems to show that the elemental structures consist of the couples of individuals caught side by side (spaced by 40 m) and those caught at hooks spaced by *ca.* 15, 20, 30, 40 and especially 25 hook-intervals (600, 800, 1,200, 1,600 and 1,000 m). The deviation of the short periodicity found in the observed values in the diagram of Series Ⅱ shows the distribution pattern of the above-mentioned elemental clusters, while that of the long periodicity represents the feature of the superior structure, which is shown more clearly in the diagram of Series Ⅰ. Namely, the population is thought to be constituted of many schools covering from 2 to 5 units (2～5 km) or thereabout. Further, this diagram also suggests conspicuously the formation of the school of higher order, which seems to be located in the range from the 140th to the 335th basket.

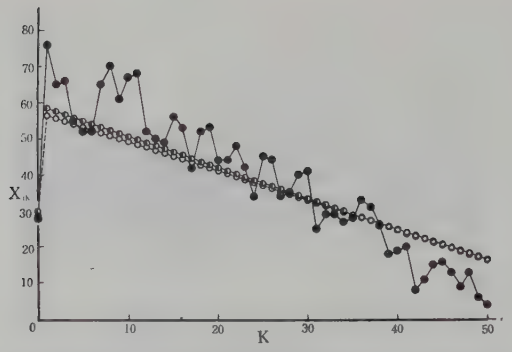


Fig. 10—4 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 4 in the Fishing Ground No. 1).

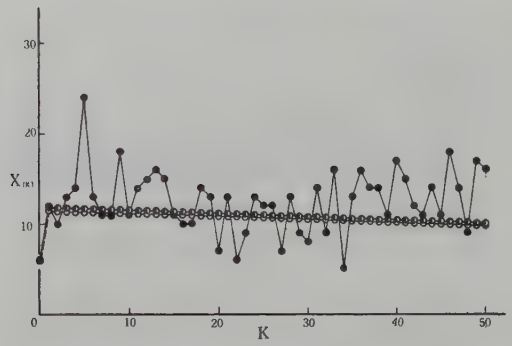


Fig. 10—4 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 4 in the Fishing Ground No. 1).

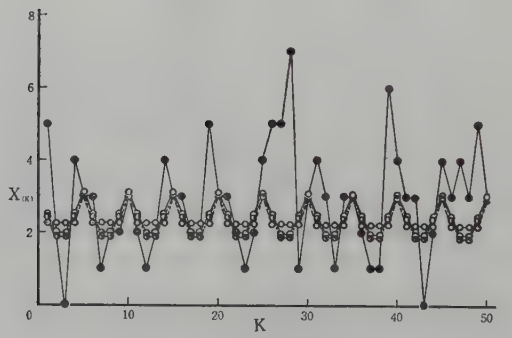


Fig. 10—4 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 4 in the Fishing Ground No. 1).

Example Y 5 : Some accidental errors are inevitably expected in treating of this example in which the total catch is extremely low, moreover, most of peaks in the diagrams of Series Ⅱ and Ⅲ indicate merely individuals themselves. So, at present, only the diagrams of Series Ⅱ and Ⅲ are shown here and any of interpretations are reserved from being mentioned. However, the diagram of Series Ⅰ suggests the existence of a school, individuals of which are widely scattered in the range covering *ca.* 35 units (35 km) and their distribution is rather self-spacing; and this school is located in the range from the 100th to the 275th basket. Besides this, there are many clusters covering 1 or 5 units (1～5 km) as the subordinate structure, although most of them are merely single or coupled individuals and only a few of them are larger ones consisting of several individuals and representing extremely scattered clusters; all of these are thought to be of the elemental structure.

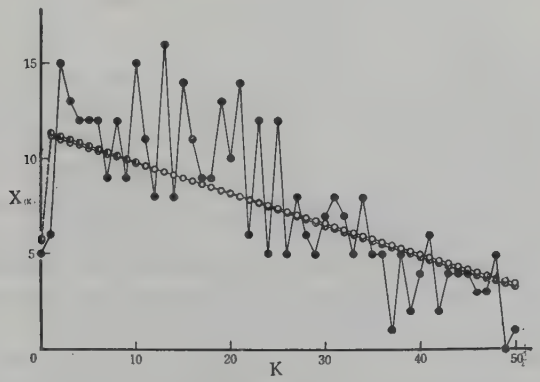


Fig. 10—5 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 5 in the Fishing Ground No. 1).

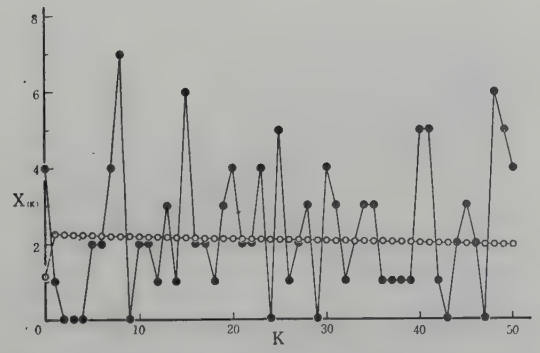


Fig. 10—5 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 5 in the Fishing Ground No. 1).

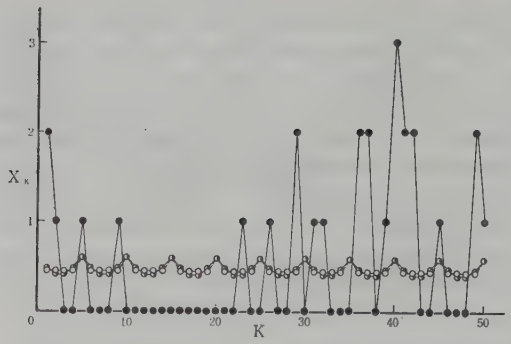


Fig. 10—5 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 5 in the Fishing Ground No. 1).

Example Y 6 : As for the diagram of Series Ⅲ, further discussions are retained, since the observed values are very scarce. Narrow peaks of the observed values in the diagram of Series Ⅱ indicate single individuals in such a case in which the catch rate is extremely low. Accordingly, the elemental structure must be deduced from the diagram of Series Ⅰ and the deviation of long periodicity found in the diagram of Series Ⅱ. And the structure consists of clusters covering from 1 unit (1 km) to 4 units (4 km) at the maximum, and most of these clusters are constituted of loosely aggregated 2 or 3 individuals, even the larger ones are constituted of less than 5 individuals. Further, the diagram of Series Ⅰ suggests the existence of schools covering 25 or 30 units (25 or 30 km) and probably being located in the ranges respectively from the 30th to the 130th basket and from the 200th to the 350th basket, although this is rather inconspicuous because of the lower catch rate.

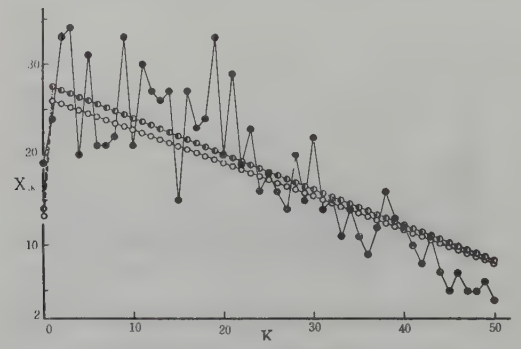


Fig. 10—6 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 6 in the Fishing Ground No. 1).

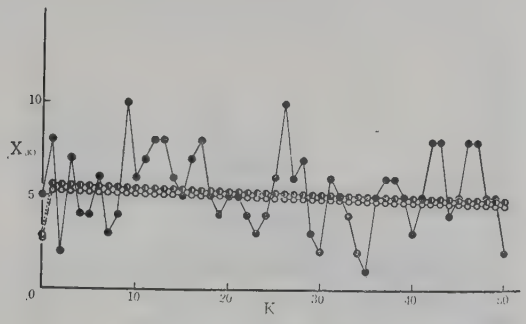


Fig. 10—6 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅱ obtained at Station 6 in the Fishing Ground No. 1).

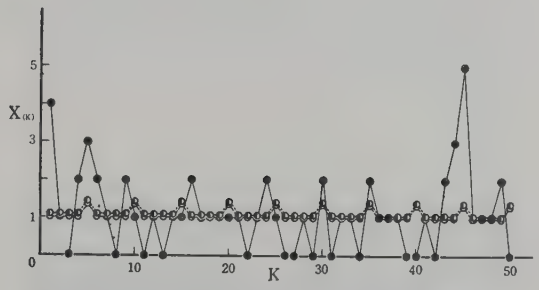


Fig. 10—6 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅲ obtained at Station 6 in the Fishing Ground No. 1).

Example Y 7 : Concerning the diagram of Series Ⅲ, no explanation is given, because both the estimated and observed values are too small, although it seems to allude to the

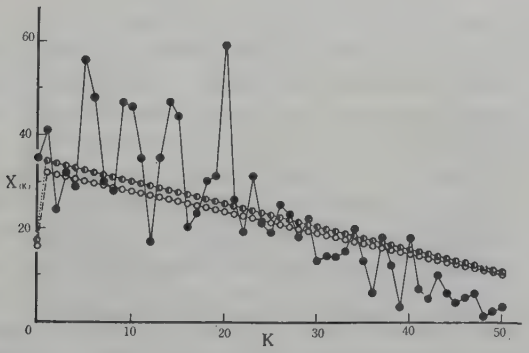


Fig. 10—7 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅰ obtained at Station 7 in the Fishing Ground No. 1).

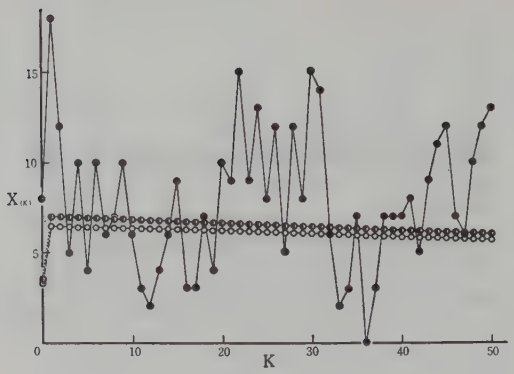


Fig. 10—7 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 7 in the Fishing Ground No. 1).

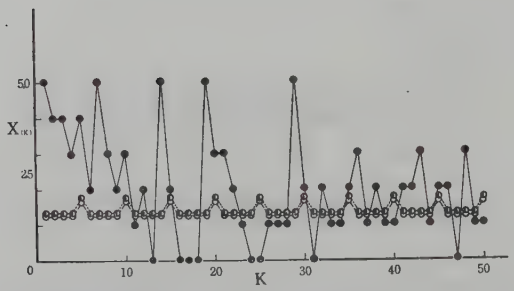


Fig. 10—7 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 7 in the Fishing Ground No. 1).

existence of large elemental clusters covering 1 or 2 baskets (200～400 m). The short periodic deviation of the observed values in the diagram of Series Ⅱ seems to indicate that the elemental structure consists of the couples of individuals caught within 2 or 3 baskets and besides them, some single individuals themselves caught widely apart from other individuals are also regarded to be bearing the character of elemental clusters. The long periodic deviation of the observed values in the same diagram and the short one in the diagram of Series Ⅰ show that the above-mentioned elemental clusters are loosely bundled into 7 or more aggregations which are, perhaps, located in the ranges from the 160th to the 180th, from the 185th to the 205th basket, around the 215th, 225th and 230th baskets, from the 255th to the 265th and from the 275th to the 280th basket. The long periodic deviation in the diagram of Series Ⅰ shows that 4 rather conspicuous and 3 obscure aggregations are, further, loosely bundled into a single widely scattered school located in the range from the 160th to the 280th basket.

Example Y 8 : Nothing is explained for the diagram of Series Ⅲ, because the occurrence of accidental errors caused by low catch rate is expected. The diagram of

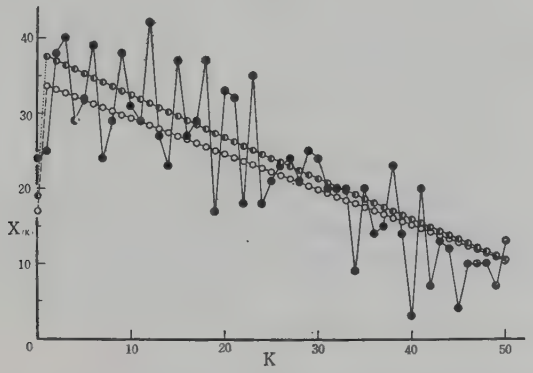


Fig. 10—8 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅰ obtained at Station 8 in the Fishing Ground No. 1).

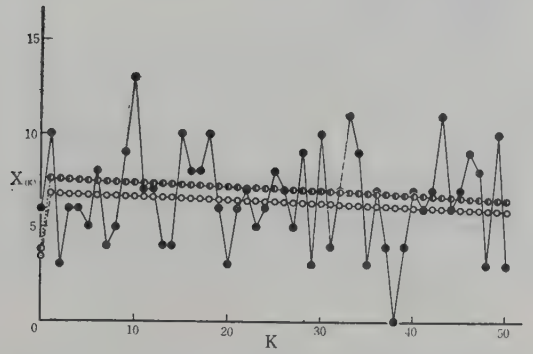


Fig. 10—8 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅱ obtained at Station 8 in the Fishing Ground No. 1).

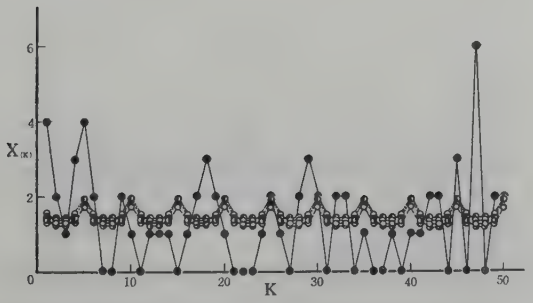


Fig. 10—8 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅲ obtained at Station 8 in the Fishing Ground No. 1).

Series I does not show any symptoms of the existence of any wide schools, although the existence of conspicuous aggregations covering 1 or 2 units (1～2 km) and being spaced by 1 or 2 units (1～2 km) is suggested. And the diagram of Series II shows that the above-mentioned aggregations are constituted of many subordinate clusters covering 1 or 2 baskets (200～400 m), most of which are, however, single individuals widely spaced and yet having the character of elemental clusters while a part of which is couples of individuals spaced rather widely.

Example Y 9 : The diagram of Series III alludes to nothing but that there are 6 couples of individuals caught side by side and this is 6 times as large as the estimated values, although a considerable accidental errors can be expected in this consideration. The diagram of Series I shows that the population seems to contain many conspicuous aggregations covering 1 or 2 and rarely 3 units. The deviation of the observed values

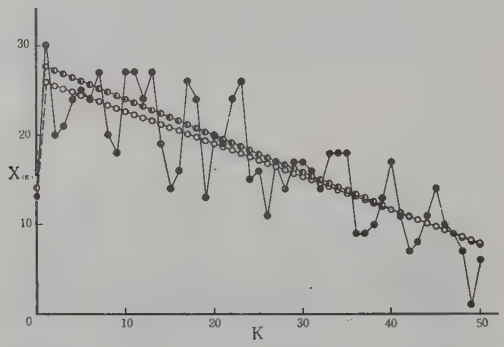


Fig. 10—9 (I). X(k)—k relation diagram of yellow-fin tuna (Series I obtained at Station 9 in the Fishing Ground No. 1).

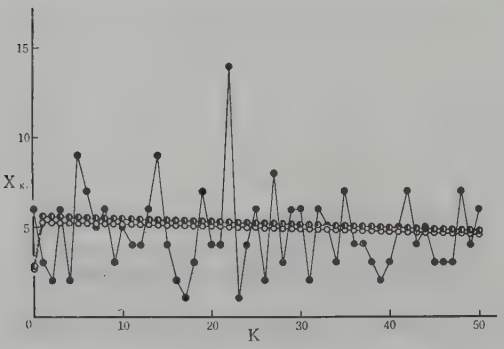


Fig. 10—9 (II). X(k)—k relation diagram of yellow-fin tuna (Series II obtained at Station 9 in the Fishing Ground No. 1).

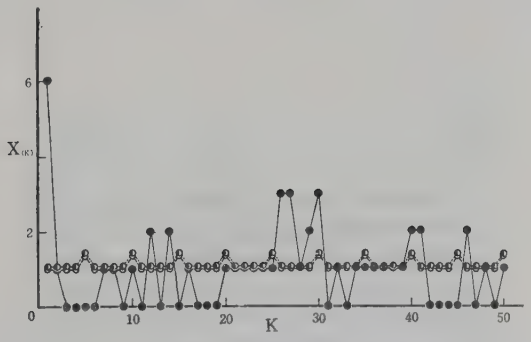


Fig. 10—9 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅲ obtained at Station 9 in the Fishing Ground No. 1).

in the diagram of Series Ⅱ represents that the above-mentioned aggregations are the bundles of widely spaced single individuals and couples of individuals caught at the hooks located near by each other, and all these are regarded as elemental clusters.

Example Y 10 : This is the example in which the gradient of distribution is the strongest of all examples about yellow-fin tuna, yet the total catch is extremely low; accordingly some accidental errors are much expected in the observed and estimated values. So the description is confined here to only the fact that the population is constituted of many aggregations located at every one unit. The word "aggregations" is used here merely for convenience' sake; actually, however, most of the "aggregations" are single individuals widely spaced and yet having the character of elemental clusters. As the catch rate is extremely low, nothing can be deduced from the diagrams of Series Ⅱ and Ⅲ.

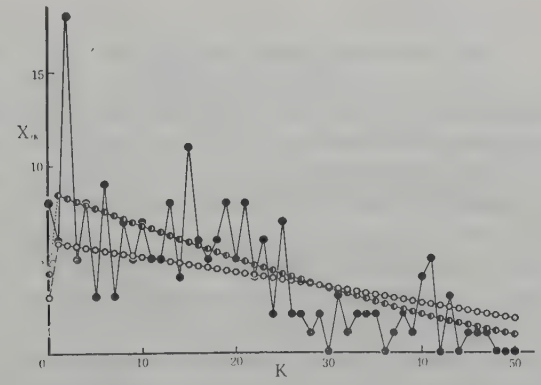


Fig. 10—10 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅰ obtained at Station 10 in the Fishing Ground No. 1).

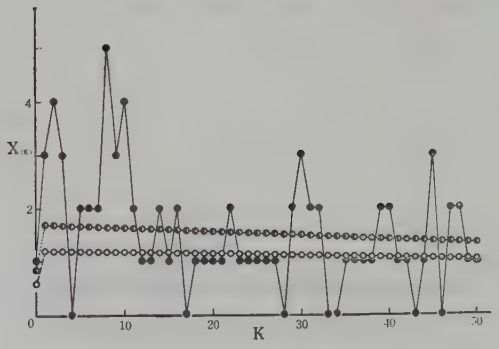


Fig. 10—10 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅱ obtained at Station 10 in the Fishing Ground No. 1).

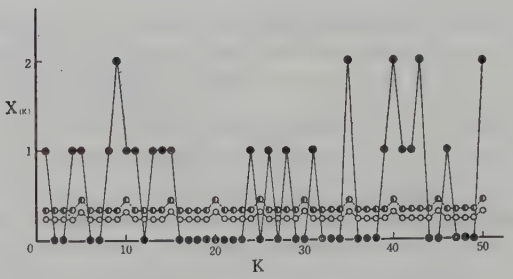
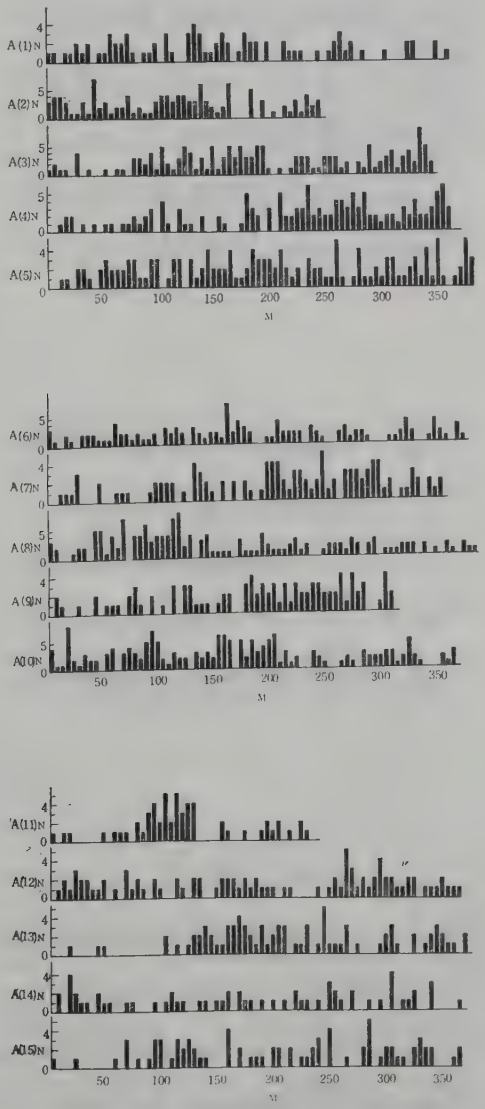


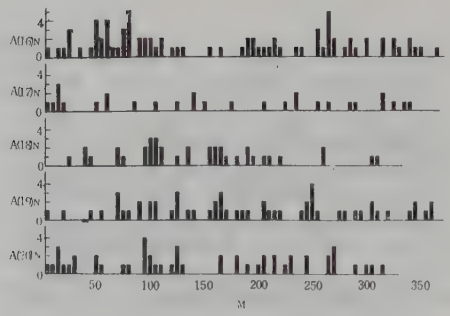
Fig. 10—10 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅲ obtained at Station 10 in the Fishing Ground No. 1).

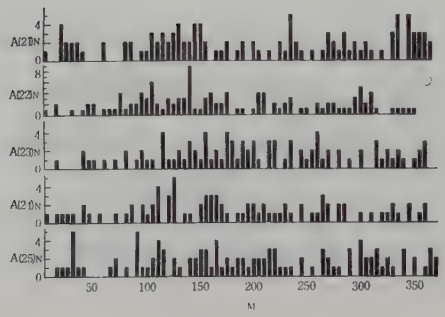
3) Albacore

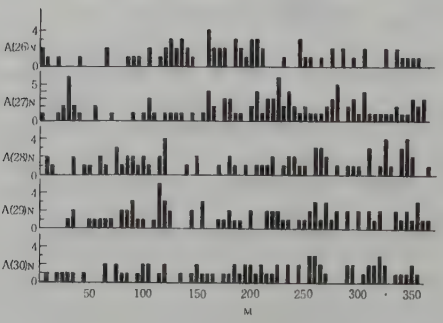
Albacore is the smallest of all commercially important kind of tuna, and considered to be a macro-plankton feeder against other tuna which are thought to be piscivora. And it is a well-known fact that the young stages of this fish can be caught by angling in the waters near the northern, or perhaps also southern, margin of its geographical distribution. But the older ones are caught only by long-lines in the waters in the inner side of its distribution range. Accordingly, this species is expected to show the highest contagiousness of the distribution pattern among all tunas. On the other hand, in order to ascertain whether the method used in this report can lead us to the right cognition of schooling tendencies of tunas or not —— in other words, to judge the results that big-eye tuna and yellow-fin tuna are distributed almost by chance —— it seems to be very adequate to examine whether the results of the examination on examples of the fish clearly forming schools and caught by the same fishing-method, long-line, show the existence of schools or not. The examples of albacore caught by long-line seem superficially

to be the most suitable for this purpose. Actually, however, the examples of off shore albacore do not show any symptom of the school formation as shown in Fig. 11.




A(16)N
A(17)N
A(18)N
A(19)N
A(20)N
50
100
150
200
250
300
350
M


A(21)N
A(22)N
A(23)N
A(24)N
A(25)N
50
100
150
200
250
300
350
M


A(26)N
A(27)N
A(28)N
A(29)N
A(30)N
50
100
150
200
250
300
350
M

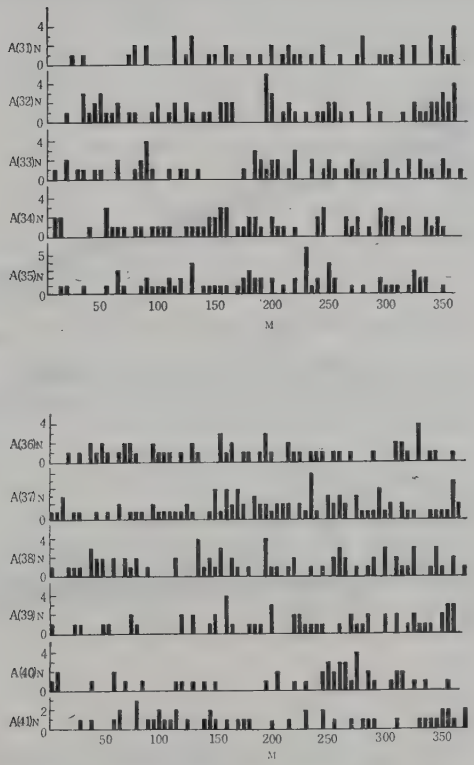


Fig. 11. Distribution of albacore in each of 5 consecutive baskets in respective examples.
Abbreviations :
M : basket number counted from the initial point of hauling.
N : number of individuals caught by respective 5 consecutive baskets.
A (x) : example of albacore obtained at the Station "x" in the Fishing Ground No. 2.

Thus, the examples of albacore are found unsuitable for the above-mentioned purpose, although they are worthy to be analyzed for the purpose of comparing the spatial relation of albacore with those of yellow-fin tuna and big-eye tuna. The distribution pattern of albacore is, thus, analyzed by the same method as that used in the cases of big-eye tuna and yellow-fin tuna. And the results show that it seems to be the characteristics of the distribution pattern of albacore that no conspicuous contagiousness is found between the two hooks arranged side by side and no elemental cluster covering wide range is observable, although its general pattern does not differ from those of big-eye tuna and yellow-fin tuna.

Exposition of particular example

Example A 1 : Small deviations of the observed values in diagrams of all 3 series indicate, together with the high catch rate which may secure less possibility of

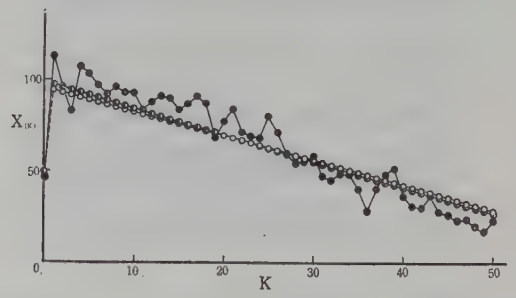


Fig. 12—1 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 1 in the Fishing Ground No.2).

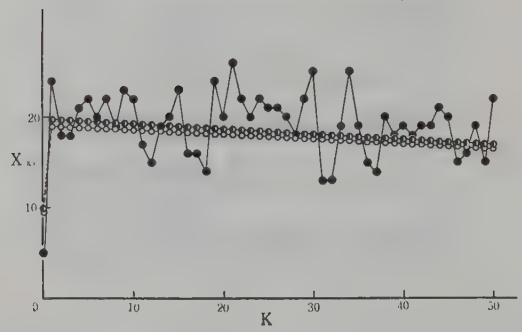


Fig. 12—1 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 1 in the Fishing Ground No.2).

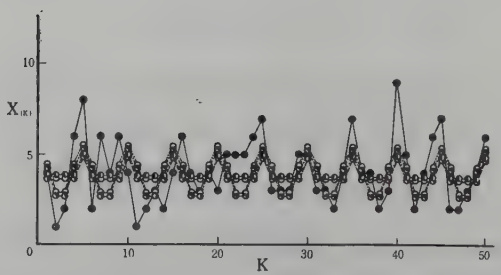


Fig. 12—1 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 1 in the Fishing Ground No.2).

accidental errors, that the discrepancy of this distribution pattern from the chance one is very small. No prominent structure observable within a short range is alluded to in the diagram of Series Ⅲ. While, the short periodic deviation of the observed values in the diagram of Series Ⅱ suggests the existence of clusters covering 2-basket width (400 m), which is respectively widely spaced single individuals or small groups consisting of less than 5 individuals, and all these are regarded as the elemental clusters. The long periodic deviation in this diagram, which corresponds to the short periodic one represented in the diagram of Series Ⅰ, suggests the weak bundle formation of these elemental clusters, covering 3 units (3 km), located at every 4 units and being constituted of 4 elemental clusters or thereabout. Bundles of elemental clusters are further aggregated into a wide but weakly contagious school covering *ca.* 25 units (25 km) and occupying the main part of the catch in this example, which may correspond to the high catch rate occurring in the range from the 60th to the 190th basket.

Example A 2 : The relatively small and interrupted deviation of the observed values in the diagram of Series Ⅲ does not allude to any structures within a short range. The distribution of peaks in the diagram of Series Ⅱ seems to represent the distribution pattern of elemental clusters which are each constituted of up to several individuals. And a single peak or a couple of peaks are corresponding to each peak in the diagram of Series Ⅰ. The long periodic deviation, though not so clear, in the diagram of Series Ⅰ alludes to the existence of 3 schools covering shorter than 10 units (10 km), which are loose bundles of the elemental clusters mentioned above; these schools seem to be located around the 10th basket, in the range from the 100th to the 150th and around the 250th basket.

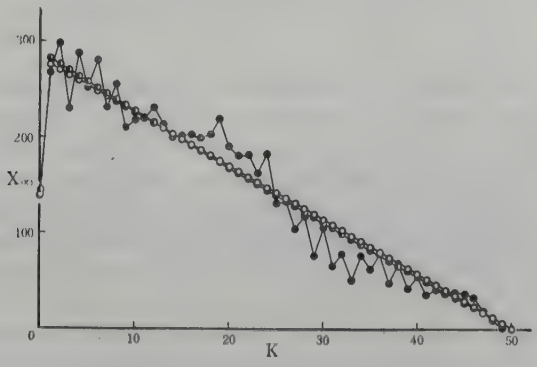


Fig. 12—2 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 2 in the Fishing Ground No.2).

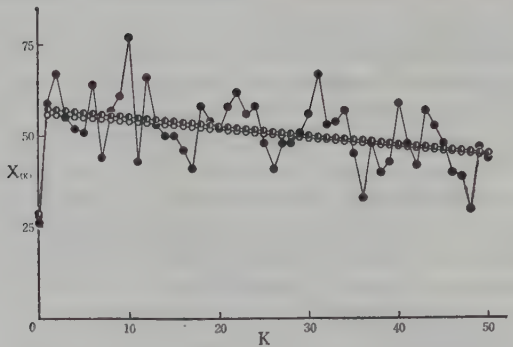


Fig. 12—2 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 2 in the Fishing Ground No.2).

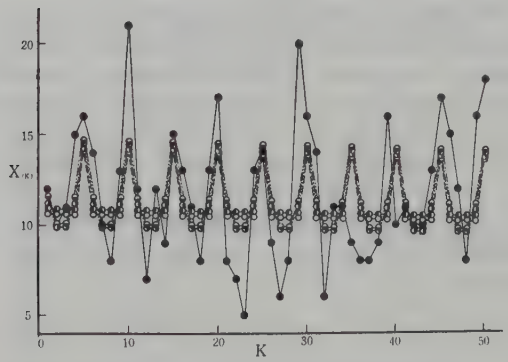


Fig. 12—2 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 2 in the Fishing Ground No.2).

Example A 3 : The diagram of Series Ⅲ does not show any detailed structures other than that shown more clearly in the diagram of Series Ⅱ. The short periodic deviation of the observed values in the diagram of Series Ⅲ shows the feature of the elemental clusters being scattered over 1 or 2 baskets (200～400 m) and mostly constituted of widely spaced single individuals, couples of individuals or occasionally up to 3～4 individuals. The long periodic deviation found in the diagram of Series Ⅲ, which corresponds to the short periodic one in the diagram of Series Ⅰ, represents the bundle formation of elemental clusters covering 1 or 2 units (1～2 km), though this is not so distinct. Besides the above-mentioned fact, the existence of 2 schools spaced by *ca.* 30 units (30 km) and other obscure ones being about 15 units (15 km) apart from each of the former is alluded to. The two schools seem to be located in the range from the 150th to the 200th and around the 350th basket, while the obscure ones indicate the portions around the 100th and 250th baskets.

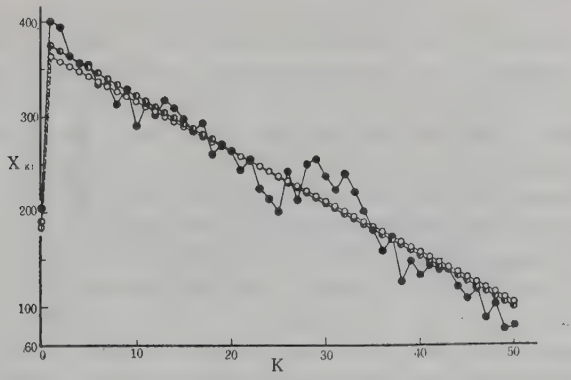


Fig. 12—3 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 3 in the Fishing Ground No.2).

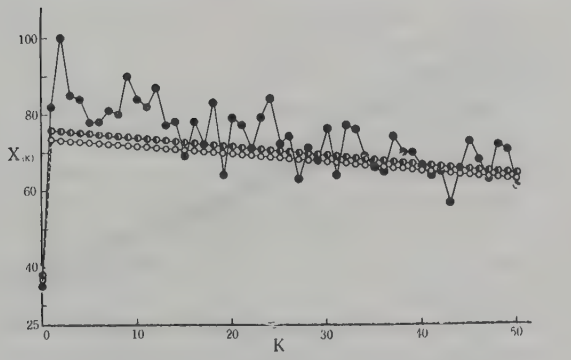


Fig. 12—3 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 3 in the Fishing Ground No.2).

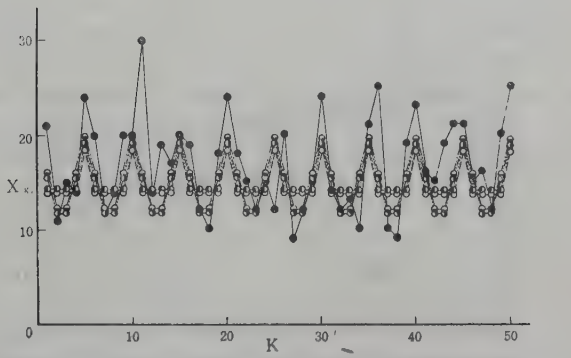


Fig. 12—3 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 3 in the Fishing Ground No.2).

Example A 4 : This is one of the typical examples in which the influences of the gradient of catch rate and the difference of catch rate according to the depth are prominent. Accordingly, the difference between the 2 series of estimated values, respectively the influence of the gradient in the diagrams of Series Ⅰ and Ⅱ is taken into consideration or not, and also the differences among the 4 series of estimated values in the diagram of Series Ⅲ —— the influences of one or both of the two factors are taken into consideration or not —— are remarkable. Moreover, it must be also noted that the most of the observed values in the diagram of Series Ⅰ are slightly lower than the estimated values in which the influence of the gradient is taken into consideration. The same fact is also shown in the diagrams of Series Ⅱ and Ⅲ, though somewhat obscurely this time. This may seem to be attributable to the over-estimation of the gradient. But, it is shown clearly in Fig. 11 that the catch rate increases abruptly around the 210th basket and it is more natural to regard this sudden increase as the influence of the existence of schools than to regard it as the

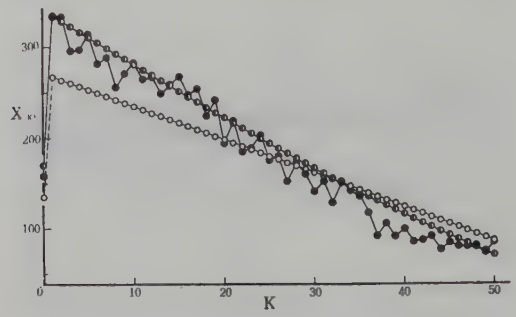


Fig. 12—4 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 4 in the Fishing Ground No.2).

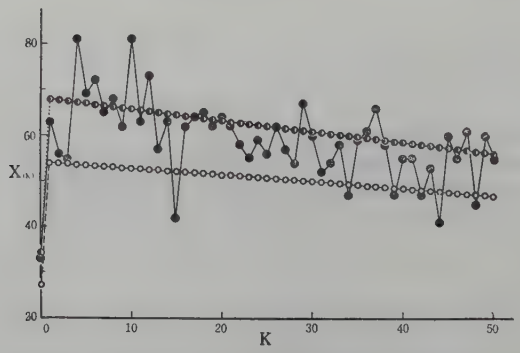


Fig. 12—4 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 4 in the Fishing Ground No.2).

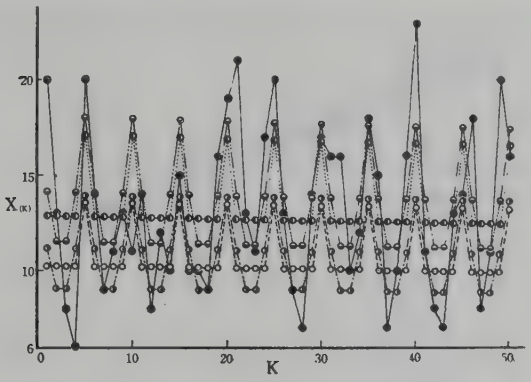


Fig. 12—4 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 4 in the Fishing Ground No.2).

effect of the increase of soaking time. And in such an example as this, the distribution is more uniform than the case in which the increase of the catch rate is simply proportional to the soaking time. Accordingly, when such a distribution is compared with the estimated value in which the increase of the catch rate is regarded as being simply proportional to the soaking time, it might be accepted as if it were self-spacing. The diagrams were decoded on the basis of the above-mentioned supposition.

The diagram of Series Ⅲ represents clearly how the estimated values are distorted by the influence of both the gradient of the catch rate and the difference of the catch rate according to depth, but it does not show anything about the distribution pattern, except that some of the elemental clusters are constituted of the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 hook (80 m), while others are covering a wider range. The distribution of peaks in the diagram of Series Ⅱ is faithfully reflecting the distribution pattern of the elemental clusters covering 1 or 2 baskets (200～400 m), and most of the clusters are actually couples of individuals spaced very widely or single individuals widely spaced and yet retaining the character of the elemental cluster. Further examination of this diagram reveals obscurely the bundle formation. The diagram of Series Ⅰ indicates that the above-mentioned elemental clusters or bundles of them show the trend to form a coarsely aggregated school covering 30 units (30 km) or more; and this school seems to be located in the range from the 200th to the 350th basket.

Example A 5 : The diagram of Series Ⅲ indicates that the number of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 basket (200 m) or thereabout is larger than that being distributed by chance and the diagram of Series Ⅱ shows that the number of individuals caught within the same basket is less than that being distributed by chance —— the occurrence of a single individual in one basket is more frequent but the occurrence of 2 or more individuals in one basket is less frequent than those found in the chance distribution. Besides the pattern given

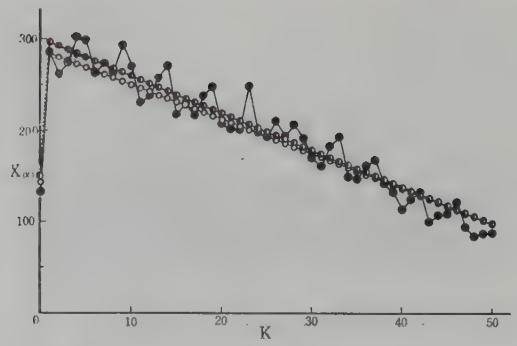


Fig. 12—5 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 5 in the Fishing Ground No.2).

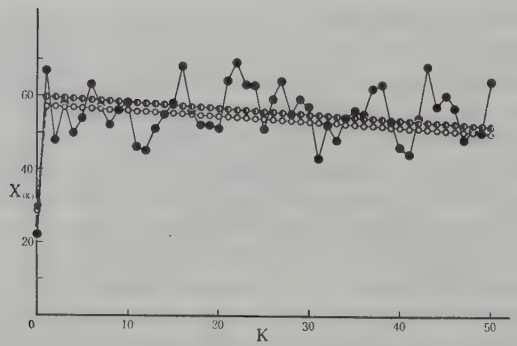


Fig. 12—5 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 5 in the Fishing Ground No.2).

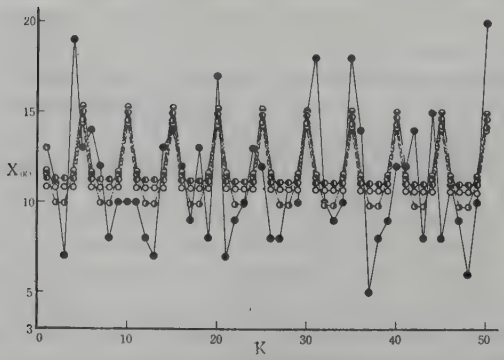


Fig. 12—5 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 5 in the Fishing Ground No.2).

above, it is also clarified that the baskets occupied by fishes or those densely occupied by fishes are met with frequently at every one basket. In the diagram of Series I, the observed values at $k = 0$ to 3 are a little lower. And this means that the number of individuals caught within 4 successive units is smaller than that estimated on the supposition that individuals are scattered by chance. While, the frequency of occurrence of the couples of individuals caught at the hooks spaced respectively by 5,9 and 10 units *etc.* is larger than that which should be found in the chance distribution. Thus, the distribution pattern is considered as follows: most individuals are scattered rather in a self-spacing manner. The number of individuals appeared even in the units where the fishes were caught densely is much less and moreover the number of such units itself is also far less than those found in the distribution in which individuals are scattered by chance; single or couples of such units are frequently observable at every 5 units or thereabout.

Example A 6 : Among the baskets occupied by fishes, those with only a single

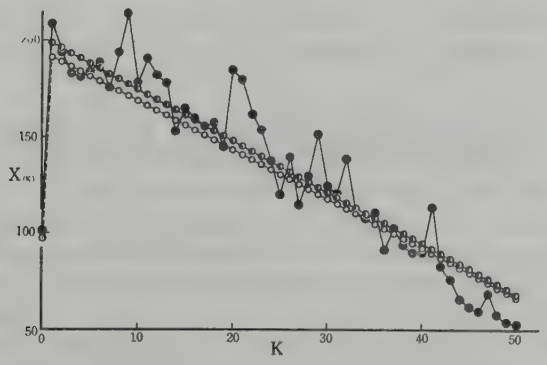


Fig. 12—6 (I). X(k)—k relation diagram of albacore
(Series I obtained at Station 6 in the Fishing Ground No.2).

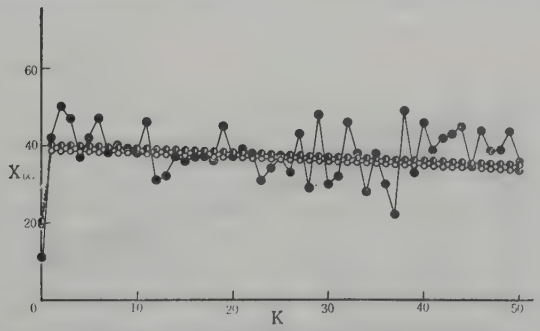


Fig. 12—6 (II). X(k)—k relation diagram of albacore
(Series II obtained at Station 6 in the Fishing Ground No.2).

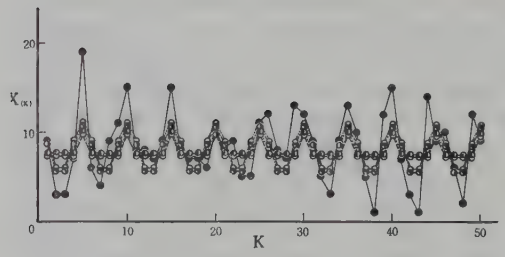


Fig. 12—6 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 6 in the Fishing Ground No.2).

individual in each are met with very frequently, while those with two or more in each are observed much less frequently, *i.e.*, the baskets are occupied in a self-spacing manner. These occupied baskets are found arranged successively or being spaced by 1 or 2 baskets (200～400 m), namely contagiously. Single of occupied baskets or bundles of them, which are all regarded as widely dispersed elemental clusters, are further aggregated into schools covering from 1 to 5 units (1～5 km) and located at every 5 units or thereabout. The existence of schools of such an order is seen rather clearly in Fig. 11.

Example A 7 : It is suggested, in the diagram of Series Ⅲ, that the elemental structure consists mostly of couples of individuals caught side by side (spaced by 40 m) or at the hooks being spaced by the width ranging from 15 to 25, about 35 and about 45 hook-intervals (600, 1,000, 1,400 and 1,800 m). The diagram of Series Ⅱ suggests that 2 or 3 successive or single isolated occupied baskets or aggregations of these baskets show the tendency to form the superior structure which is, however, constituted of merely less than several individuals. The diagram of Series Ⅰ indicates the existence of a school covering *ca.* 20 units (20 km), which seems to be constituted of 5 or 6 subordinate aggregations, mentioned above; the school seems to be located in the range from the 200th to the 300th basket, while its subordinate aggregations are

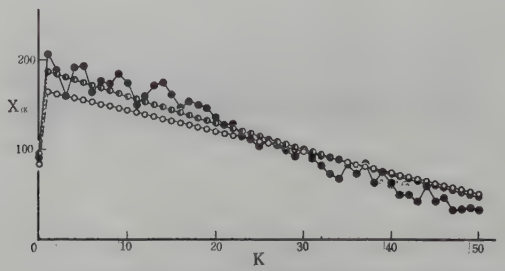


Fig. 12—7 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 7 in the Fishing Ground No.2).

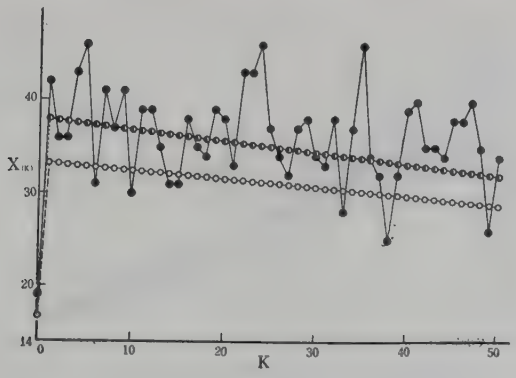


Fig. 12—7 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 7 in the Fishing Ground No.2).

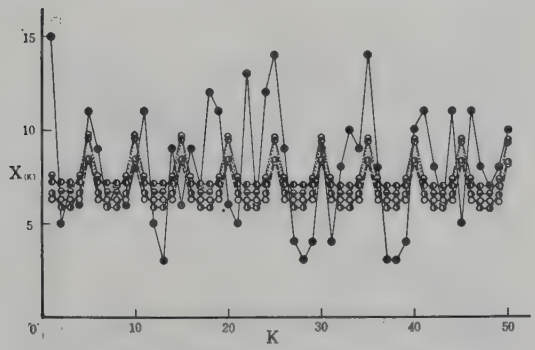


Fig. 12—7 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 7 in the Fishing Ground No.2).

situated in the ranges respectively from the 190th to the 210th basket, from the 215th to the 230th basket, from the 235th to the 260th basket, from the 270th to the 285th basket and from the 290th to the 310th basket. Such aggregations are also observable outside the school.

Example A 8 : Most of the observed values in the diagrams of Series Ⅱ and Ⅲ take a little higher values than the estimated ones on account of the existence of the conspicuous school mentioned below. Therefore, the above-mentioned fact must be kept in consideration, when the subordinate structure is pursued. Now the existence of considerably wide elemental clusters is certified by the analysis made on the diagram of Series Ⅲ. And the short periodic deviation of the observed values in the diagram of Series Ⅱ represents more clearly the distribution pattern of the elemental structure, which is shown only obscurely in the diagram of Series Ⅲ. Several clusters of 1 basket width (200 m), most of which are respectively a single isolated

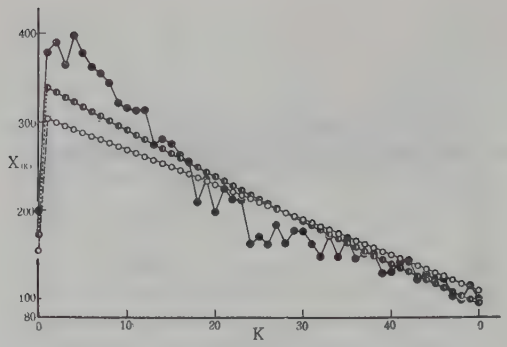


Fig. 12—8 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 8 in the Fishing Ground No.2).

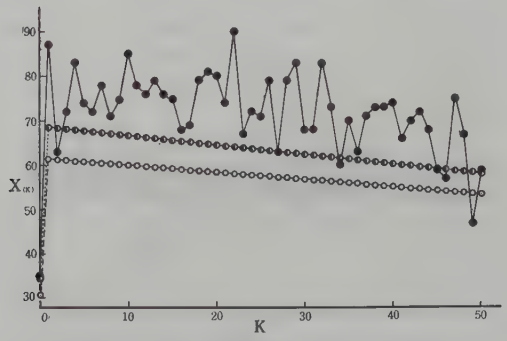


Fig. 12—8 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 8 in the Fishing Ground No.2).

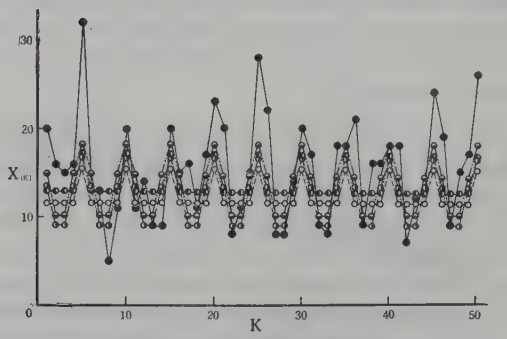


Fig. 12—8 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 8 in the Fishing Ground No.2).

individual or a couple of individuals regarded as the elemental clusters, and those of wider width regarded as the bundles of the above-mentioned clusters are further bundled into obscure aggregations which correspond to the short periodic deviation of the observed values in the diagram of Series Ⅰ. The high observed values continuously found in the range from $k = 0$ to 17 in the diagram of Series Ⅰ represent clearly the existence of a relatively strongly aggregated school covering 17 units (17 km), which seems to be situated in the range from the 50th to the 140th basket.

Example A 9 : The diagram of Series Ⅲ does not show any clear structures. While, the diagram of Series Ⅱ shows that several clusters of 1 basket width (200 m), most of which are single isolated individuals or couples of them, are bundled into aggregations covering from 1 to 3 units (1～3 km) and being spaced by 1 unit (1 km); this can be seen more clearly in the diagram of Series Ⅰ. The diagam of Series Ⅰ indicates the existence of a loosely aggregated school covering *ca.* 20 units (20 km) and being

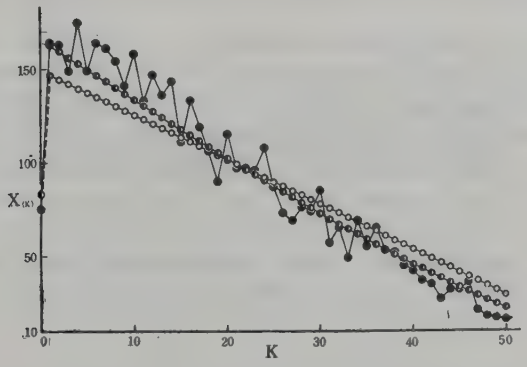


Fig. 12—9 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 9 in the Fishing Ground No.2).

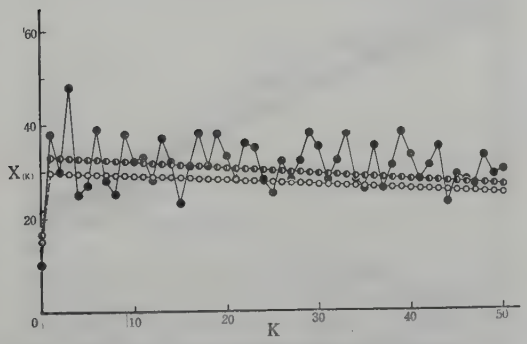


Fig. 12—9 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 9 in the Fishing Ground No.2).

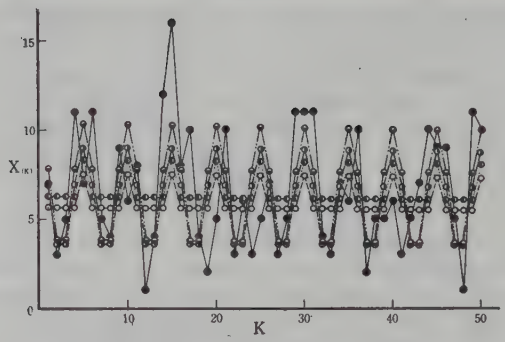


Fig. 12—9 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 9 in the Fishing Ground No.2).

considered to be located in the range from the 180th to the 280th basket.

Example A 10 : The contagiousness extending to a considerable width is suggested in the diagram of Series Ⅲ. This diagram and that of Series Ⅱ indicate that the elemental clusters covering from 1 to 4 baskets (200～800 m), of which single individuals and couples of them caught side by side (spaced by 40 m) or at the hooks spaced by 1 basket (200 m) are the principal ingredients besides some of longer width, are bundled into aggregations covering *ca.* 3 units (3 km) as seen also in the diagram of Series Ⅰ. This diagram of Series Ⅰ represents further that some of the aggregations are loosely gathered into a school covering *ca.* 30 units (30 km) and being considered to be located in the range from the neighbourhood of the 70th to the 230th basket.

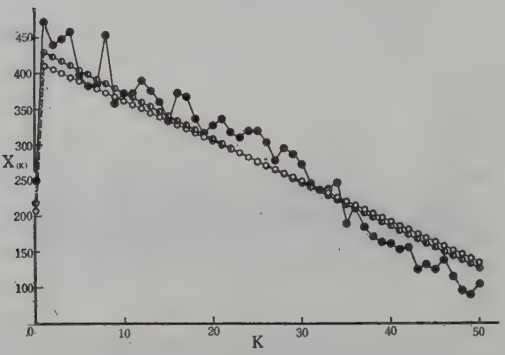


Fig. 12—10(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 10 in the Fishing Ground No.2).

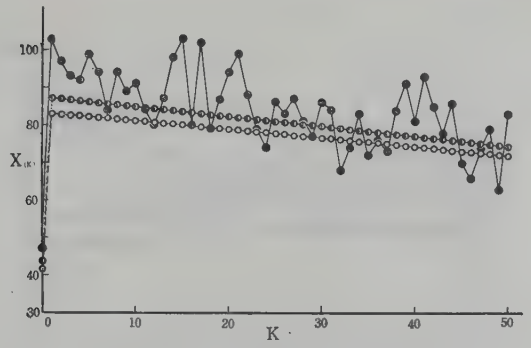


Fig. 12—10(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 10 in the Fishing Ground No.2).

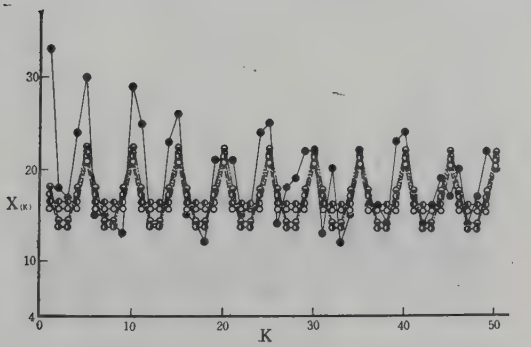


Fig. 12—10(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 10 in the Fishing Ground No.2).

Example A 11 : This is one of the typical examples in which the existence of schools is represented exactly. Namely the existence of conspicuous schools covering *ca.* 8

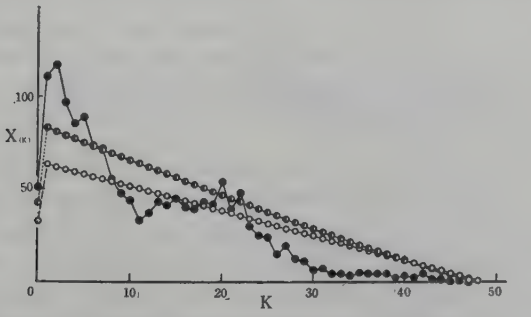


Fig. 12—11(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 11 in the Fishing Ground No.2).

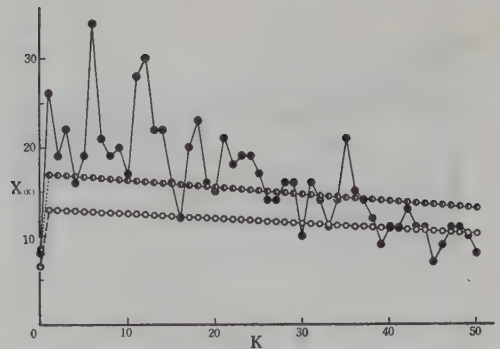


Fig. 12—11(Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 11 in the Fishing Ground No.2).

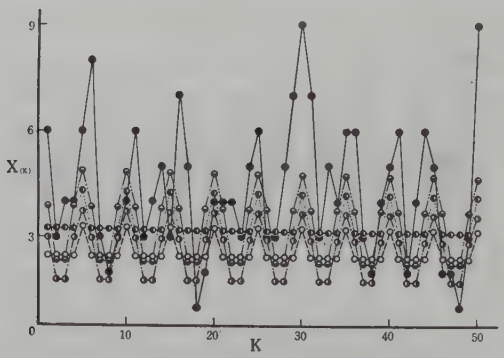


Fig. 12—11(Ⅲ). X(k)—k relation diagram of albacore (Series Ⅲ obtained at Station 11 in the Fishing Ground No.2).

units (8 km) and being spaced by *ca.* 20 units (20 km) was confirmed, and the most distinct one of which is situated around the 100th basket, while the groups of individuals hooked around the first and the 200th basket may be regarded as obscure ones. The diagrams of Series Ⅱ and Ⅲ show that the above-mentioned schools are composed of many subordinate clusters covering from 1 to 5 baskets (200 m ~ 1 km) and being regarded as the elemental clusters.

Example A 12 : The diagrams of Series Ⅱ and Ⅲ show that principal ingredients of elemental clusters are single isolated individuals or couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 hook (80 m) and perhaps also couples of individuals caught at the hooks spaced by 5 (1 km) or more baskets. These elemental clusters are bundled so loosely that the number of individuals hooked within the same unit may be accepted as self-spacing. Such a pattern can be seen when a wide and dense school is caught and nearly all hooks are occupied by fishes, but the

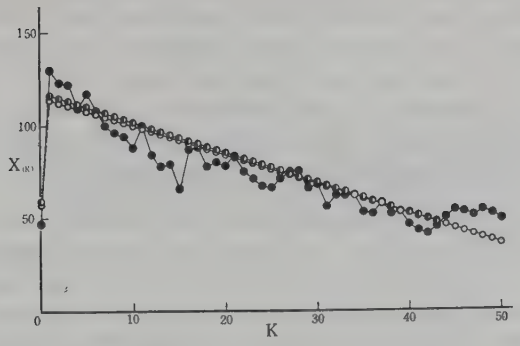


Fig. 12—12(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 12 in the Fishing Ground No.2).

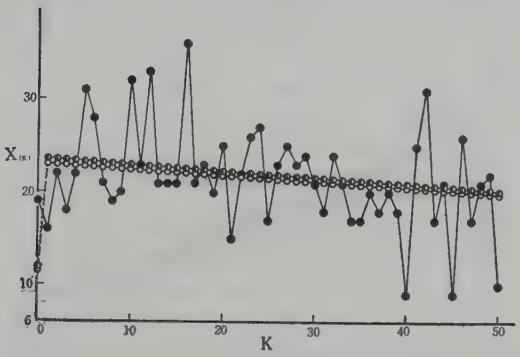


Fig. 12—12(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 12 in the Fishing Ground No.2).

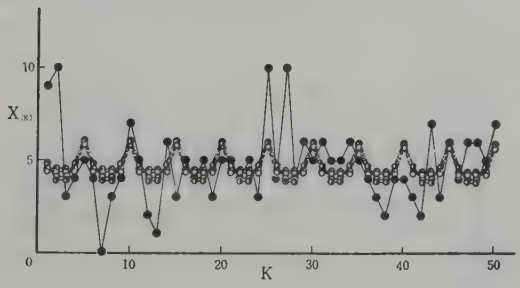


Fig. 12—12(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 12 in the Fishing Ground No.2).

number of individuals hooked in the same unit cannot reach beyond the number of hooks. But the more crucial examination of the data reveals that there are found

unoccupied hooks even in the parts regarded as portions where a school was caught, consequently the above-mentioned self-spacing must be assigned to the essential pattern of the distribution. The existence of two relatively distinct schools, the centers of which are apart from each other about 50 units (50 km), and one somewhat obscure school-like aggregation located between them is sustained. These schools are considered to indicate the higher catch rates found around the 25th and 300th baskets, while the school-like aggregation corresponds to that around the 115th basket.

Example A 13 : The mode of the deviation of the observed values in the diagram of Series Ⅲ is shown more clearly in the diagram of Series Ⅱ, because the estimated values in the former contain the essential and regular deviation, while this is not the case about the latter. Thus, no information other than that shown in the diagram of Series Ⅱ can be deduced from the diagram of Series Ⅲ. The deviation of the observed values in the diagram of Series Ⅱ is regular and rather long as compared with that of other examples, and shows that elemental clusters, including single isolated individuals, are most frequently situated at every 3 or thereabout baskets. The diagram of

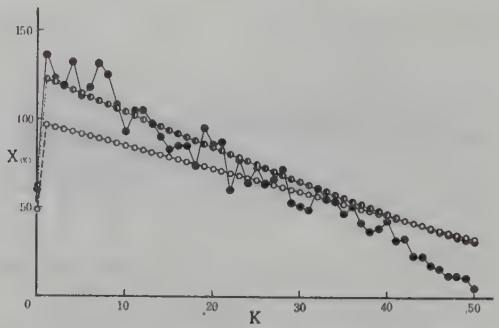


Fig. 12—13(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 13 in the Fishing Ground No.2).

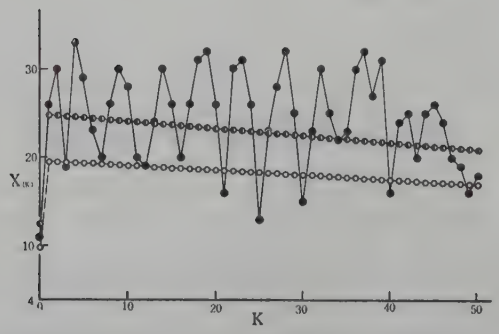


Fig. 12—13(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 13 in the Fishing Ground No.2).

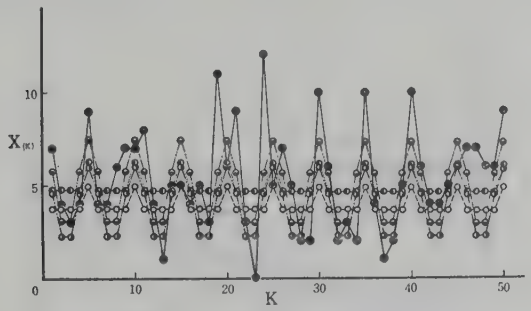


Fig. 12—13(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 13 in the Fishing Ground No.2).

Series Ⅰ indicates that these elemental clusters or bundles of them are further gathered into many aggregations covering from 1 to 3 units (1～3 km), although some of which are constituted each of a single of the above-mentioned components. Of these aggregations, those located around the 250th, 300th and 350th basket are corresponding to the high observed values at respectively $k=20$, 28 and from 32 to 36, while those located successively in the range from the 130th to the 210th basket are represented as the successive higher observed values at $k=0$ to 14 in the diagram of Series Ⅰ, which suggest the existence of a school of *ca.* 14-unit width (14km).

Example A 14 : This is an example of the intrinsically self-spacing population, so that even in most of the occupied units merely a single individual was caught, being mingled with a few extremely scattered schools of narrow width. The diagram of Series Ⅱ offers further data for the analysis and shows that, taking both the total catch and total number of hooks together into consideration, the essential structure consists of the couples of individuals caught in adjoining baskets (spaced by shorter than 400 m) or those being spaced by 10 baskets (2 km), although actual number of

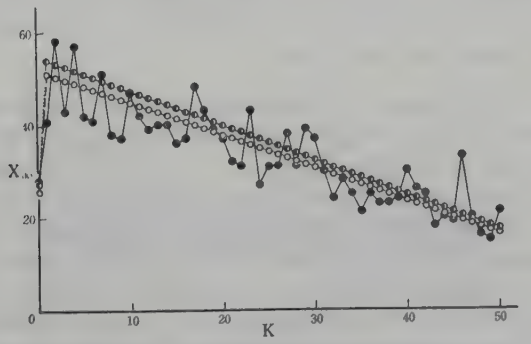


Fig. 12—14(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 14 in the Fishing Ground No.2).

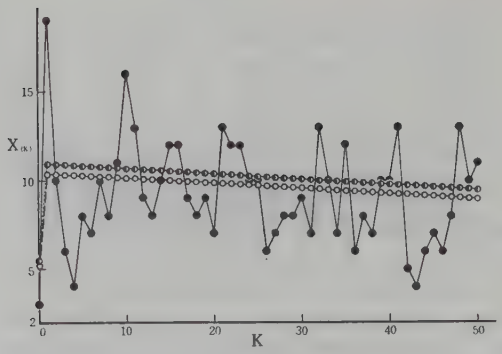


Fig. 12—14(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 14 in the Fishing Ground No.2).

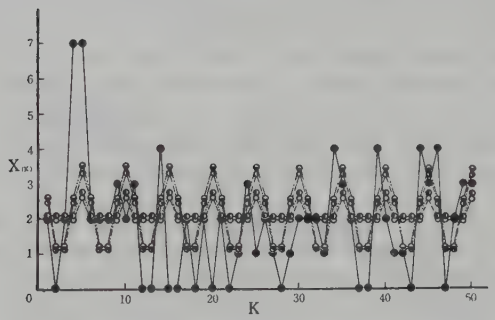


Fig. 12—14(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 14 in the Fishing Ground No.2).

such couples is not so large. And the diagram of Series Ⅲ, in which some accidental errors are highly expected, shows the average interval between the individuals of the former couples more in detail, which is estimated to be as long as 1 basket (200 m) or 1 hook-interval longer than that (240 m).

Example A 15 : The structure of this example is, roughly speaking, considered to consist of the basic population being composed of randomly distributed individuals and many aggregations which cover from 1 to 3 units (1～3 km) and are constituted of several individuals at the maximum. The details are supplemented by the diagrams of Series Ⅱ and Ⅲ and it becomes clear that the population and aggregations are constituted of many clusters covering shorter than 1 unit (1 km), in fact, most of them are merely isolated single individuals and the rests consist each of 2 or rarely more individuals. The principal ingredients of the clusters consisting of two individuals are couples of individuals caught at the hooks arranged side by side (spaced by 40 m) or at the hooks spaced by one basket (200 m) or by the distance longer than 2 but shorter

than 3-basket width (400~600 m).

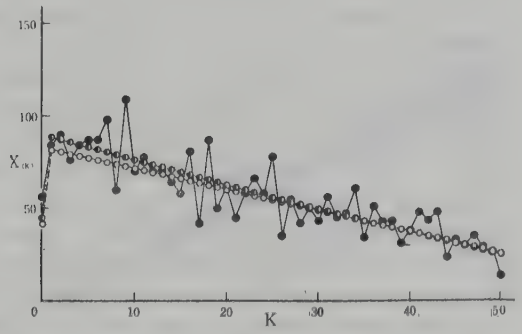


Fig. 12—15(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 15 in the Fishing Ground No.2).

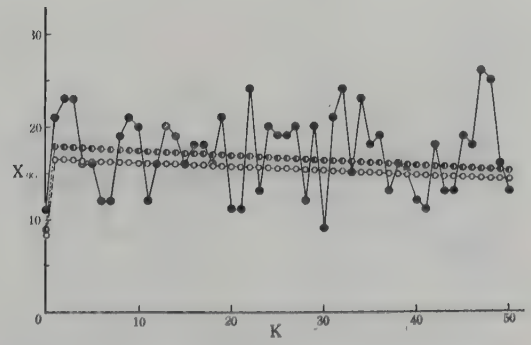


Fig. 12—15(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 15 in the Fishing Ground No.2).

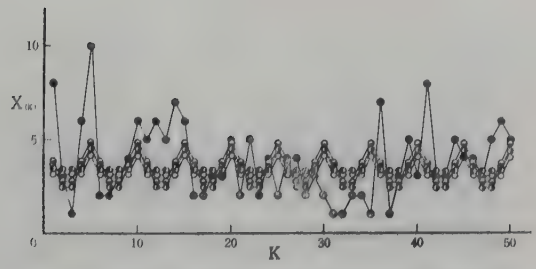


Fig. 12—15(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 15 in the Fishing Ground No.2).

Example A 16 : The diagrams of Series Ⅱ and Ⅲ, together with Fig. 11, give the following detailed structure that the population is constituted chiefly of isolated

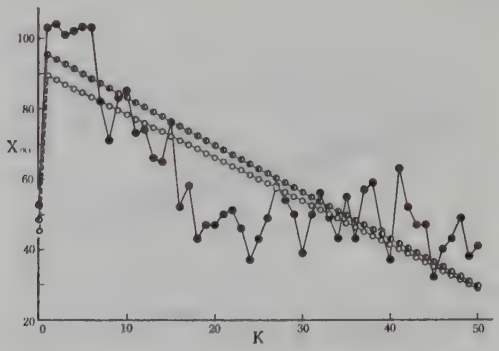


Fig. 12—16(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 16 in the Fishing Ground No.2).

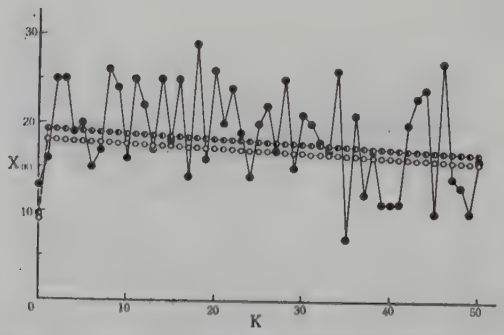


Fig. 12—16(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 16 in the Fishing Ground No.2).

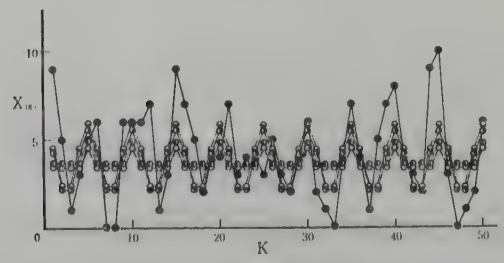


Fig. 12—16(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 16 in the Fishing Ground No.2).

single individuals and partly of couples of individuals or a little larger clusters, all of these are regarded as the elemental clusters. Moreover, the principal ingredients of the latter two are couples of individuals caught side by side (spaced by 40 m). The higher observed values at $k>10$ in Series Ⅲ indicate respectively about the inter-cluster structure, namely the above-mentioned elemental clusters are observed most frequently being spaced by $2\sim3$ ($400\sim600$ m) or $8\sim9$ baskets ($1.6\sim1.8$ km). The long periodic deviation of the observed values in the diagram of Series Ⅱ and the short periodic one in the diagram of Series Ⅰ show that bundles of elemental clusters or occasionally single isolated clusters themselves seem to form aggregations of superior structure covering from 1 to 4 units ($1\sim4$ km). The long periodic deviation in the diagram of Series Ⅰ represents clearly the existence of a school, a little conspicuous and covering 7 units (7 km) and located around the 60th basket, besides another school consisting of loose bundles of the above-mentioned aggregations, being spaced by about 30 units (30 km) from the conspicuous school and indicating the subsequent part after the 185th basket.

Example A 17 : The extremely low catch rate and the scarcity of the units in which

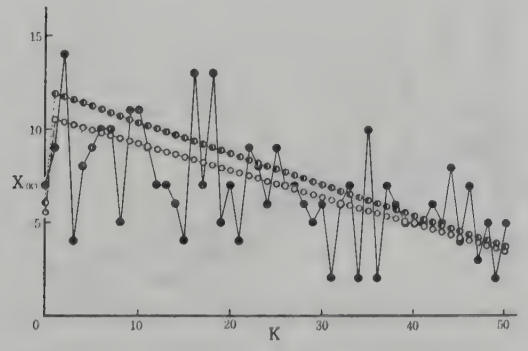


Fig. 12—17(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 17 in the Fishing Ground No.2).

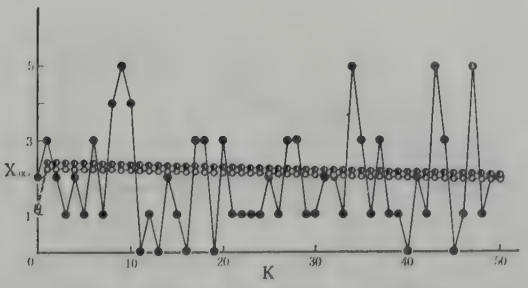


Fig. 12—17(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 17 in the Fishing Ground No.2).

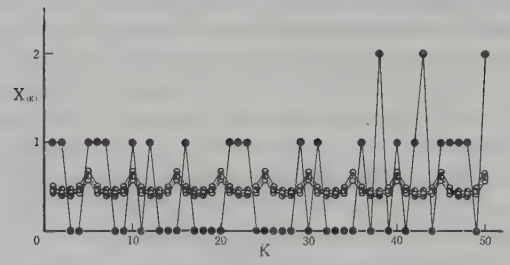


Fig. 12—17(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 17 in the Fishing Ground No.2).

two or more individuals are caught, make it impossible to deduce any trends of the distribution pattern other than the population seems to be essentially self-spacing.

Example A 18 : In order to avoid the influence of the accidental errors, nothing is

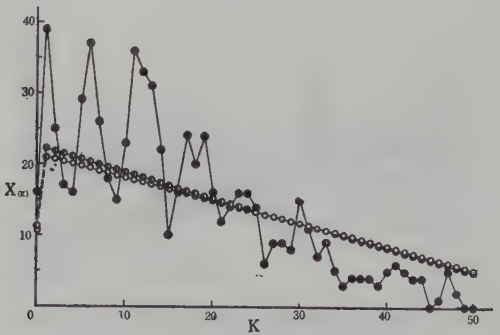


Fig. 12—18(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 18 in the Fishing Ground No.2).

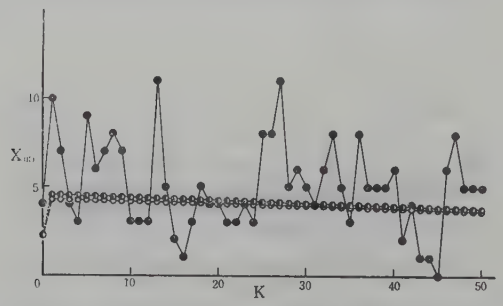


Fig. 12—18(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 18 in the Fishing Ground No.2).

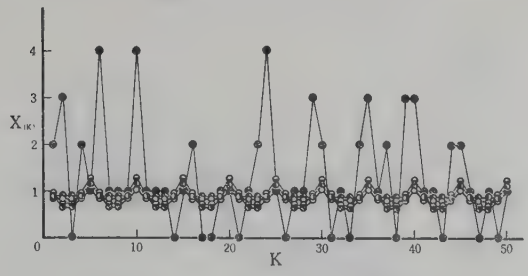


Fig. 12—18(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 18 in the Fishing Ground No.2).

explained here about the diagram of Series Ⅲ. The smaller peaks in the diagram of Series Ⅱ represent the distribution pattern of elemental clusters actually consisting mostly of single isolated individuals or couples of them, and the long periodic deviation of the observed values in the same diagram suggests the superior structure that the above-mentioned elemental clusters are rather compactly bundled into aggregations covering 3 or 4 units (3～4 km), the feature of which is shown more clearly in the diagram of Series Ⅰ. Besides, the existence of a school covering *ca.* 25 units (25 km) is certified by this diagram; this school is considered to be a loose bundle of the above-mentioned aggregations and may correspond to the part of higher catch rate in the range from the 100th to the 220th basket and the subordinate aggregations seem to be located around the 100th, 130th, 160th, 180th and 200th baskets.

Example A 19 : The scarcity of both estimated and observed values, which is attributable to the low catch rate, makes it impossible to give any consideration to the diagram of Series Ⅲ. In the diagram of Series Ⅱ, the part at $k > 5$ seems to represent the inter-unit relation, while the part at $k < 5$ indicates the intra-unit one. As there are only 13 units in which two or more individuals are caught, it is hardly

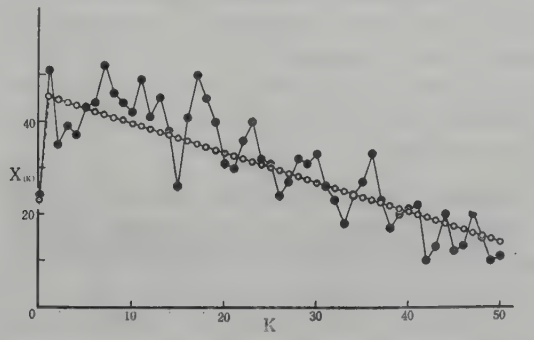


Fig. 12—19(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 19 in the Fishing Ground No.2).

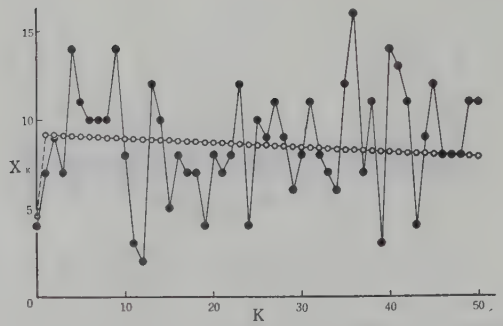


Fig. 12—19(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 19 in the Fishing Ground No.2).

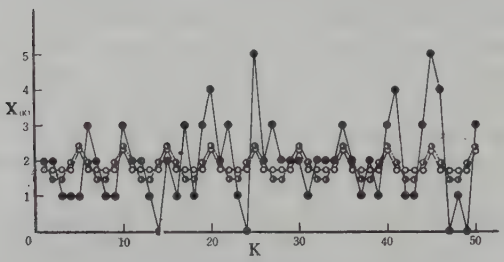


Fig. 12—19(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 19 in the Fishing Ground No.2).

possible to deduce out any facts about the intra-unit distribution other than it is rather self-spacing, namely judging from both of the total catch and the total number of units, the units respectively occupied by only a single individual occur more frequently, while those occupied by two or more individuals do less frequently than they are expected in the chance distribution. The population of this example seems to be composed of many aggregations covering from 1 to 4 units (1～4 km) and scattering along the whole row of gears. These aggregations are considered to be composed of several individuals at the maximum and represent respective blocks of occupied units found in Fig. 11.

Example A 20 : Nothing is deducible from the diagram of Series Ⅲ, because the accidental errors are highly expected. The long periodic deviation of the observed values in the diagram of Series Ⅱ shows that single isolated individuals, bundles of them or couples of individuals caught at the hooks spaced by 1,2 or 3 units (1,2 or 3 km), which are all regarded as the elemental clusters and represented by small peaks in this diagram, are loosely bundled and form aggregations covering from 1 to 3 units (1～3 km), which are shown clearly in the diagram of Series I and may corre-

spond to respective blocks of occupied units found in Fig. 11.

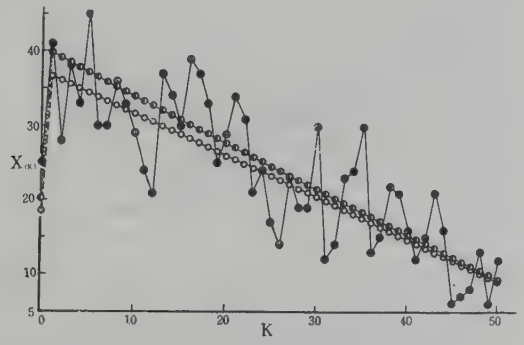


Fig. 12—20(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 20 in the Fishing Ground No.2).

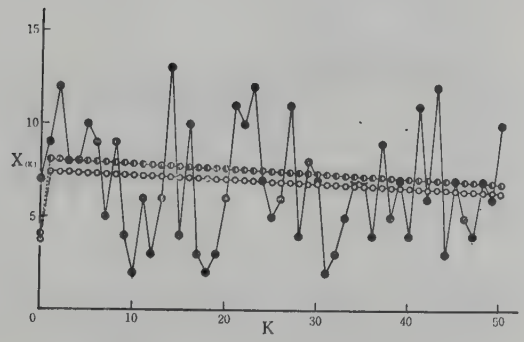


Fig. 12—20(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 20 in the Fishing Ground No.2).

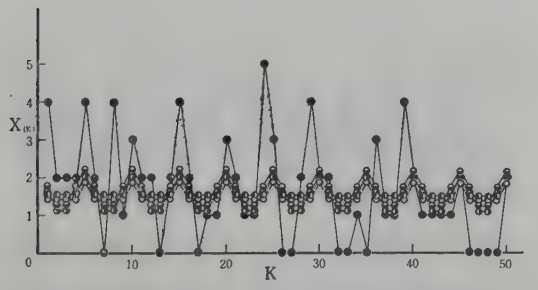


Fig. 12—20(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 20 in the Fishing Ground No.2).

Example A 21 : The influence of the difference of the catch rate according to the

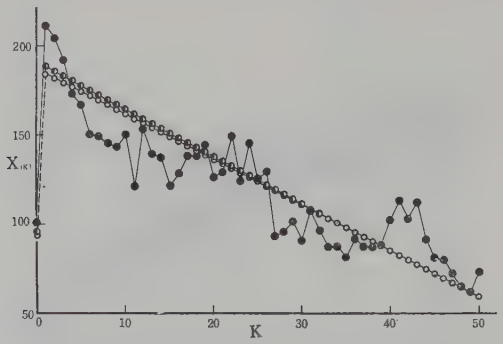


Fig. 12—21(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 21 in the Fishing Ground No.2).

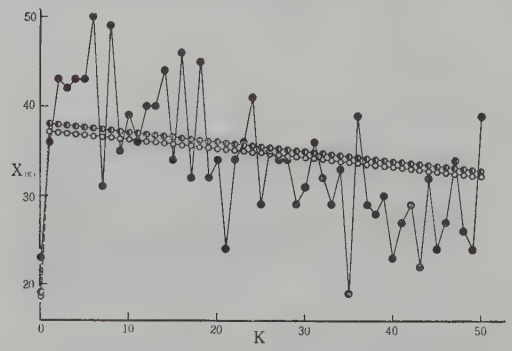


Fig. 12—21(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 21 in the Fishing Ground No.2).

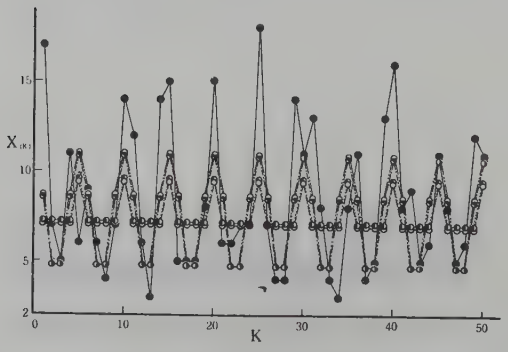


Fig. 12—21(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 21 in the Fishing Ground No.2).

depth is prominent. Accordingly, if we compare the series of the observed values with that of the estimated ones in which the influence of the difference of the catch rate according to the depth is not taken into consideration, the population will show a false 5 hook-interval (200 m) periodicity. However, when the observed values are compared with the series of the estimated values in which the effect of the depth is taken into consideration, this false 5 hook-interval periodicity becomes obscure, although the periodicity remains still very faintly. And it is deduced from the diagram of Series Ⅲ that the elemental structures comprise, besides single isolated individuals, many of the couples of individuals caught side by side or at the hooks spaced by 2, 3, 4, 5, 6, and 8 baskets. The short periodic deviation of the diagram of Series Ⅱ shows quite the same results as those described above somewhat more clearly. And the gradual decrease of the observed values in Series Ⅱ is also represented clearly in the diagram of Series Ⅰ. The higher observed values found at $k=0$ to 4 in the diagram of Series Ⅰ indicate that schools of 4 units width (4 km) or thereabout are contained in the population and they are considered to indicate the blocks of densely occupied units located around the 25th, 225th and 350th baskets. The existence of two other wide but loosely bound schools spaced by 24 (24 km) and 42 units (42 km) from the above-mentioned schools is suggested; they are considered to be located around the 125th and 275th baskets respectively.

Example A 22 : The observed values in the diagram of Series Ⅰ show a weak periodicity of the width a little shorter than 7 units (7 km). And this may be caused by the fact that the units densely occupied by fishes are found around the 75th basket —— (spaced by 6 units) —— the 105th —— (7 units) —— the 140th —— (7) —— the 175th —— (6) —— the 205th —— (6) —— the 235th —— (7) —— the 270th —— (8) —— the 310th baskets, namely at regular intervals in other words in the manner of self-spacing, although the units showing the catch rate at the same level are also found the 95th, 160th and 295th baskets. The subordinate structure is hardly deducible from the diagram of Series Ⅰ, but the details of the structure

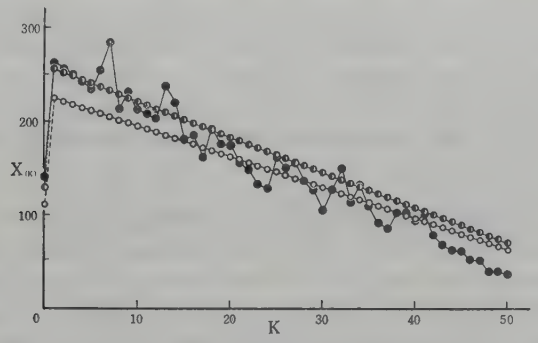


Fig. 12—22(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 22 in the Fishing Ground No.2).

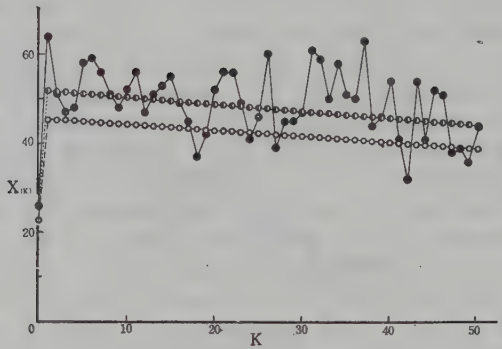


Fig. 12—22(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 22 in the Fishing Ground No.2).

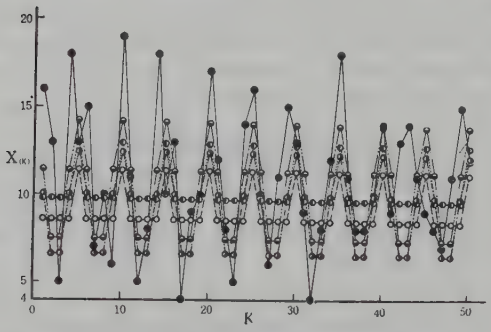


Fig. 12—22(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 22 in the Fishing Ground No.2).

can be analyzed by treating the second and third series of analyses together; the population is considered to be constituted of many clusters of the shorter width than 1 unit (=5 baskets=25 hook-intervals = 1 km). And the clusters of such a size are regarded as single isolated individuals or couples of individuals, among the latter the couples caught side by side (spaced by 40 m), at the hooks spaced by 1 hook (80 m) or the pairs of hooks of the same order in several neighbouring baskets are the most abundant.

Example A 23 : Nothing is deducible from the diagram of Series Ⅲ other than the facts obtained in the range at $k=0$ to 10 in the diagram of Series Ⅱ. The diagram of Series Ⅱ shows that the population is considered to be the assemblage of many clusters of 1,2 or 3-basket width (200, 400 or 600 m), which are mostly single individuals or couples of them and bound so weakly that even the number of individuals caught within successive 3 baskets (600 m), including that within the same basket

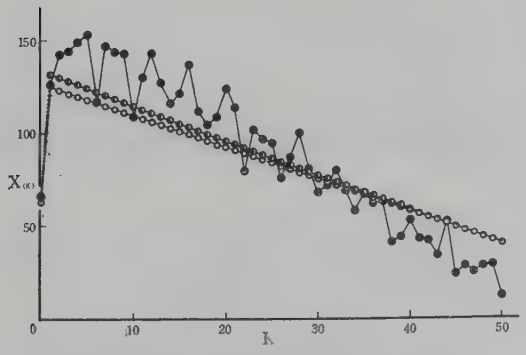


Fig. 12—23(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 23 in the Fishing Ground No.2).

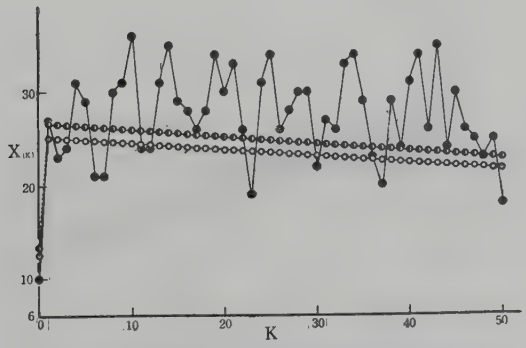


Fig. 12—23(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 23 in the Fishing Ground No.2).

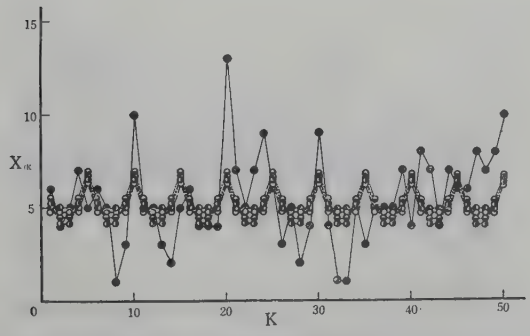


Fig. 12—23(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 23 in the Fishing Ground No.2).

(200 m), is lower than that expected in the chance distribution. The continuously high observed values found in the diagram of Series I represent the existence of a school covering *ca.* 30 units (30 km) which is constituted of 8 subordinate aggregations of *ca.* 3-unit width (3 km); this school seems to be located in the range roughly from the 105th to the 260th basket and the subordinate aggregations are considered to be situated around the 115th, 140th, 155th, 175th, 200th, 215th, 230th and 260th baskets respectively.

Example A 24 : The diagram of Series Ⅲ indicates that, besides many single isolated individuals, couples of individuals caught side by side (spaced by 40 m), at the hooks spaced by 1 hook (80 m) or at the pairs of the hooks of the same order in several successive baskets or the pairs formed by the hook of a certain order and that of the penultimate order in several successive baskets are prominent in the population. But, the diagram of Series Ⅱ of this example gives quite the same results as those described in Example A 23. Namely, the population contains a school covering about

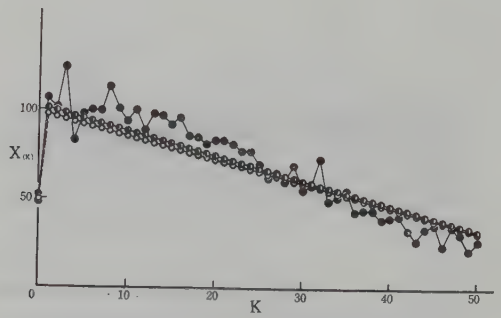


Fig. 12—24(Ⅰ). X(k)—k relation diagram of albacore (Series Ⅰ obtained at Station 24 in the Fishing Ground No. 2).

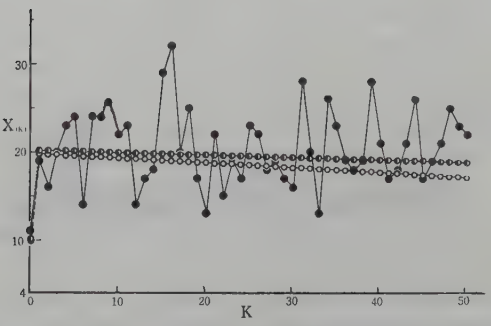


Fig. 12—24(Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 24 in the Fishing Ground No. 2).

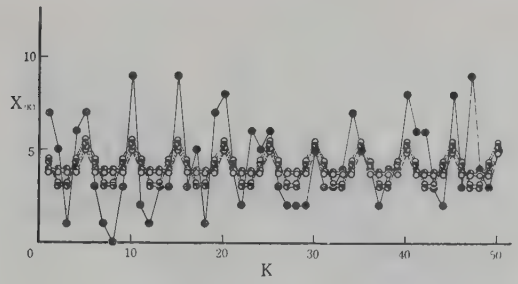


Fig. 12—24(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 24 in the Fishing Ground No.2).

25 units (25 km) and being distributed in the range from the 100th to the 235th basket.

Example A 25 : The diagram of Series Ⅲ indicates that such elemental clusters as couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by shorter than 1 basket (200 m) or thereabout, 3 (600 m) or the width from 6 to 9 baskets (1.2～1.8 km) are observed more frequently than those in the chance distribution. The long periodic deviation of the observed values in the diagram of Series Ⅲ suggests that several single individuals or elemental clusters mentioned above, which are represented by the short periodic one in the same diagram and the latter are constituted of less than 2～3 individuals, are bundled to form aggregations represented by the short periodic one of the observed values in the diagram of Series Ⅰ. The diagram of Series Ⅰ alludes to the existence of a school covering *ca.* 35 units (35 km) and being constituted of loose bundles of rather longer subordinate aggregations. The consecutive units of higher catch rate in the range from the 140th to the 235th basket are considered to be an assemblage of several aggregations forming the main part of the school, while those around the 100th and 275th baskets are also taken each as a small part of the school; those around the 30th, 310th and 365th baskets

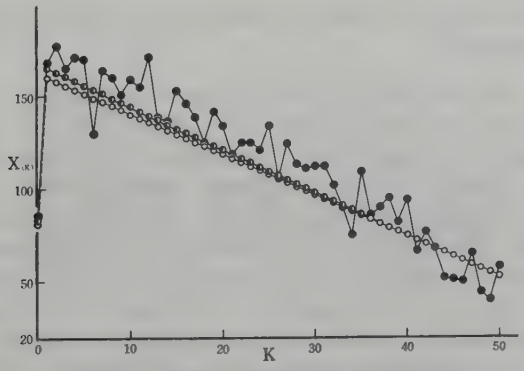


Fig. 12—25(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 25 in the Fishing Ground No.2).

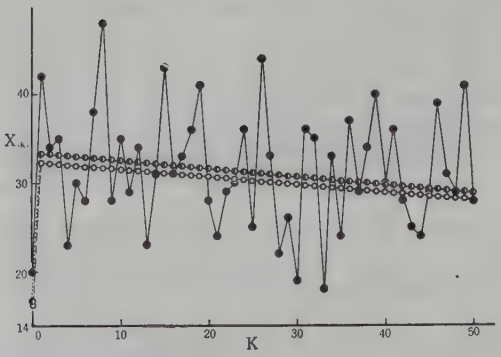


Fig. 12—25(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 25 in the Fishing Ground No.2).

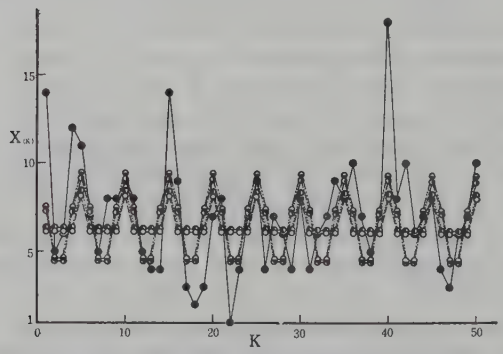


Fig. 12—25(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 25 in the Fishing Ground No.2).

are thought to illustrate the existence of subordinate aggregations, although they are located outside the school.

Example A 26 : The diagram of Series Ⅲ suggests, although there are expected some accidental errors, that the elemental structure comprises a number of couples of individuals spaced by shorter than 1 basket (200 m) or the width of 2 ~ 3 or 7 baskets (400 ~ 600 m or 1.4 km) besides single isolated individuals; this is certified also by the large amplitude of the short periodic deviation of the observed values in the diagram of Series Ⅱ. The existence of a school covering *ca.* 20 units (20 km) is alluded to in the diagram of Series Ⅰ; this may indicate the units of higher catch rate observed in the range from the 115th to the 215th basket and is regarded as a loose bundle of subordinate aggregations of 1 unit width (1 km) or thereabout and representing single elemental clusters mentioned above or bundles of them.

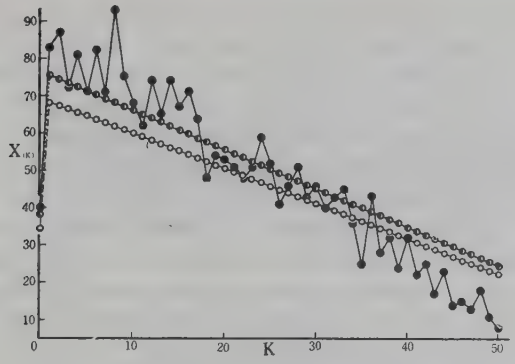


Fig. 12—26(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 26 in the Fishing Ground No.2).

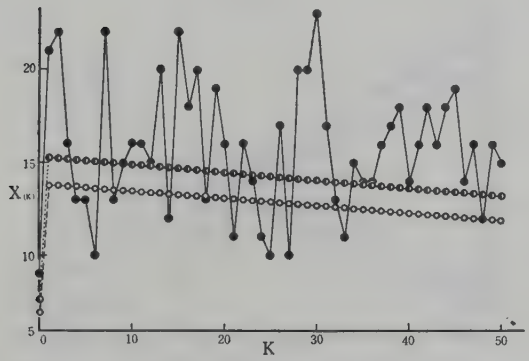


Fig. 12—26(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 26 in the Fishing Ground No.2).

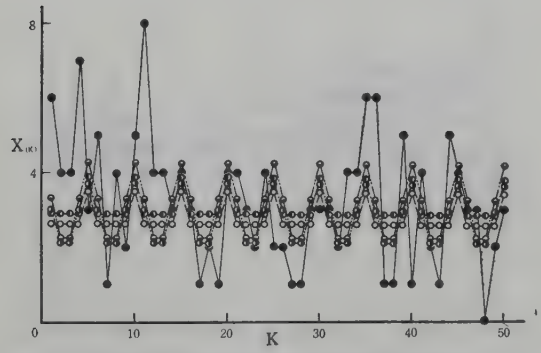


Fig. 12—26(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 26 in the Fishing Ground No.2).

Example A 27 : Although the distribution of individuals in Fig. 11 alludes to the existence of a school of a considerable width, this can be regarded as being caused by the gradient of the soaking time. Individuals tend to form many clusters covering from 1 to 3 units (1 ～3 km) or longer as it is assumable on the diagram of Series Ⅰ. The diagram of Series Ⅱ indicates that individuals are scattered more evenly within the same basket than in the chance distribution, but the number of individuals caught within 5 consecutive baskets or that caught in pairs at the hooks spaced by 7 ～9 (1.4～1.8 km) or 11～13 baskets (2.2～2.6 km) are observed more frequently than those in the chance distribution. By consulting the diagram of Series Ⅲ, the above-mentioned feature becomes clearer in detailed structure, as the number of individuals caught at the 3 consecutive hooks next to respective occupied hooks is less, while that of individuals caught in couples at the hooks spaced by 1 ～3 baskets is more abundant than those in the chance distribution.

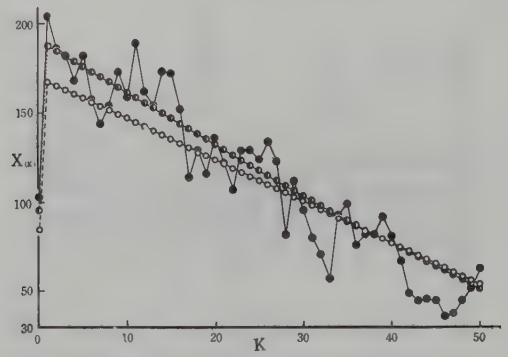


Fig. 12—27(Ⅰ). X(k)—k relation diagram of albacore (Series Ⅰ obtained at Station 27 in the Fishing Ground No. 2).

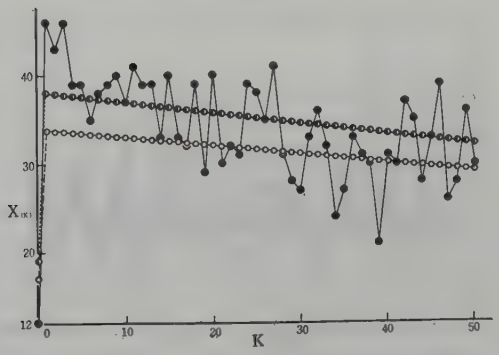


Fig. 12—27(Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 27 in the Fishing Ground No. 2).

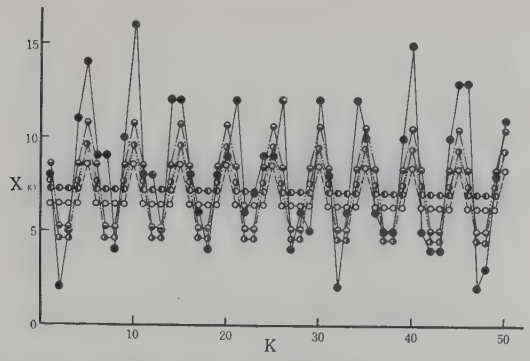


Fig. 12—27(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 27 in the Fishing Ground No.2).

Example A 28 : As for the third series of analysis, only the diagram is given here,

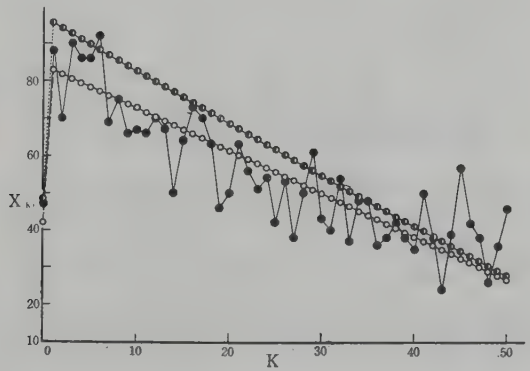


Fig. 12—28(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 28 in the Fishing Ground No.2).

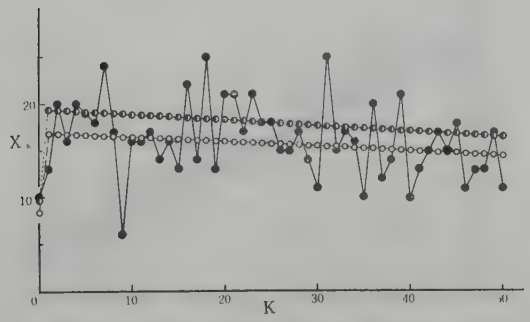


Fig. 12—28(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 28 in the Fishing Ground No.2).

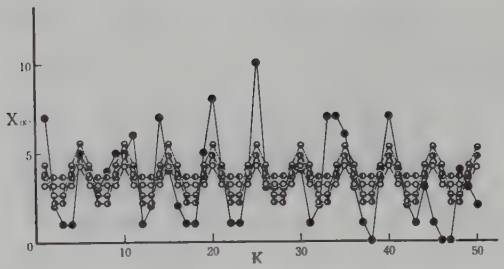


Fig. 12—28(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 28 in the Fishing Ground No.2).

although some detailed structure might be analyzed, since some accidental errors are expected. The diagram of Series Ⅱ suggests that the number of individuals caught within 6 consecutive baskets (1.2 km) is smaller, but that caught in couples at the hooks spaced by 7 baskets (1.4 km) is larger than those in the chance distribution and that the population seems to be constituted chiefly of many individuals or clusters, perhaps couples of individuals covering shorter than 1 basket (200 m). The diagram of Series Ⅰ indicates that in this example, individuals are distributed in respective occupied units more evenly and moreover, these are also spaced themselves more evenly than in the chance distribution.

Example A 29: As it is possible that accidental errors occur, nothing can be discussed about the distribution pattern on the diagram of Series Ⅲ, except that couples of individuals caught at the hooks spaced by about 1, 4, 5, 9 or 10 baskets (0.2, 0.8, 1.0, 1.8 or 2.0 km) occur more frequently than those in the chance distribution. The diagram of Series Ⅱ, which also alludes to the above-mentioned trends, suggests that the aggregations shown in the diagram of Series Ⅰ contain several individuals or

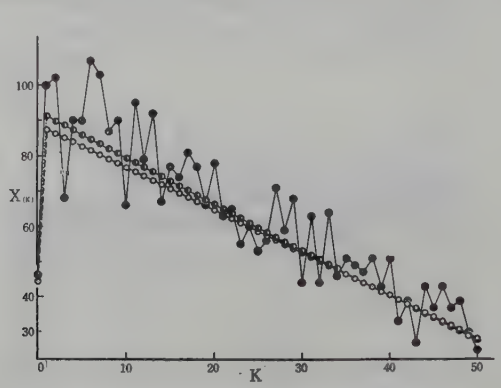


Fig. 12—29(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 29 in the Fishing Ground No.2).

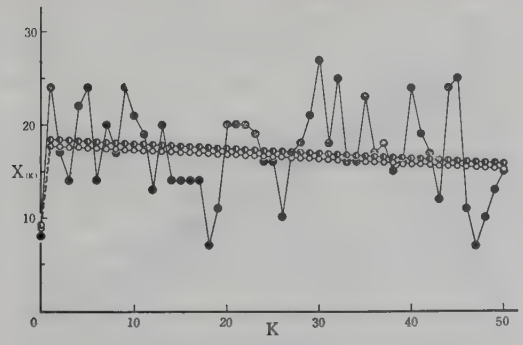


Fig. 12—29(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 29 in the Fishing Ground No.2).

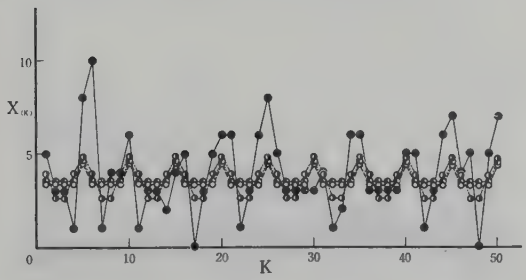


Fig. 12—29(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 29 in the Fishing Ground No.2).

subordinate clusters which are considered most probably to be couples of individuals. In the population constituted of many individuals and aggregations covering 1 or 2 units (1 or 2 km), the presence of 3 schools is discerned; they are loose bundles of the above-mentioned aggregations, cover 20, 15 and 5 units (20, 15 and 5 km) and are arranged being spaced by 30 and 45 units (30 and 45 km) respectively between their centers, though they can not be said to be segregated from one another so clearly. They seem to indicate the consecutive units of higher catch rate observed in the ranges from the 50th to the 125th, from the 200th to the 250th and around the 350th baskets respectively.

Example A 30 : As shown in Fig. 11, the population is so scattered that the number of individuals caught within the same unit is less than that in the chance distribution. Yet, several schools covering from 2 to 4 units (2~4 km) are discernible in it and besides them, clusters of 1 unit width (1 km) representing mostly couples of individuals occur being mingled with them. From the diagram of Series Ⅱ, it is presumable that the number of other individuals caught within the same occupied basket and the next one is extremely scarce, *i. e.*, the individuals are distributed in a self-spacing

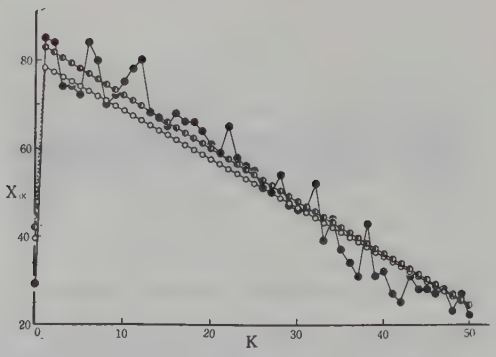


Fig. 12—30(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 30 in the Fishing Ground No.2).

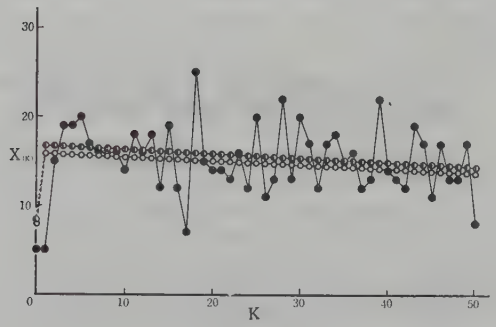


Fig. 12—30(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 30 in the Fishing Ground No.2).

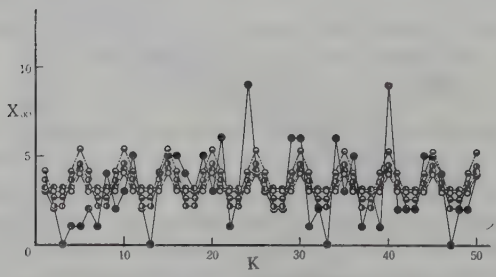


Fig. 12—30(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 30 in the Fishing Ground No.2).

manner and that the population seems to be constituted of many single isolated individuals. As the self-spacing distribution covers a considerably wide hook-intervals and both the observed and estimated values are very low on account of the low catch rate, nothing is deducible from the diagram of Series Ⅲ.

Example A 31: The low catch rate makes it impossible to give any consideration to the structure of the population upon the diagrams of Series Ⅱ and Ⅲ, except that couples of individuals spaced by about 10 (2 km), the width from 20 to 30 (4～6 km) and about 35 baskets (7 km) are rather remarkable. But, the diagram of Series Ⅰ makes it clear that the existence of clusters covering 1 unit (1 km) among the population showing the self-spacing distribution is discernible, although most of them are, in fact, single individuals or couples of them and even the largest ones among them are constituted of less than 4 individuals.

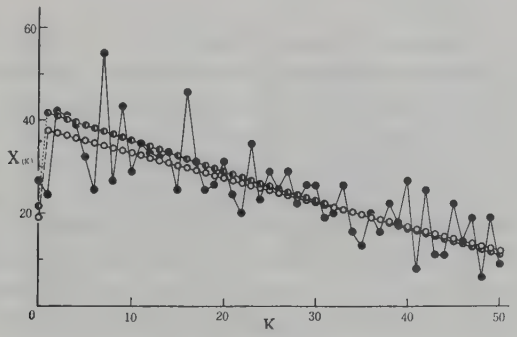


Fig. 12—31(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 31 in the Fishing Ground No.2).

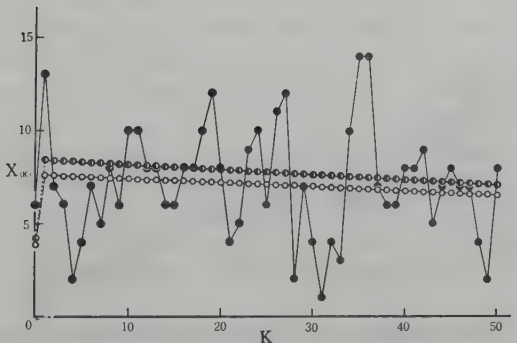


Fig. 12—31(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 31 in the Fishing Ground No.2).

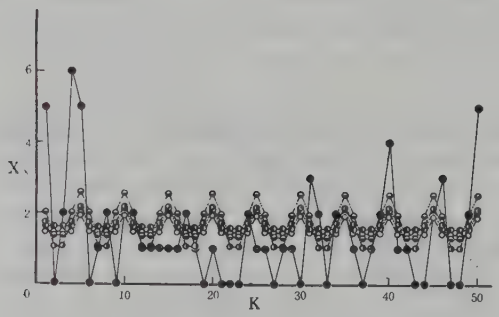


Fig. 12—31(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 31 in the Fishing Ground No. 2).

Example A 32 : The diagram of Series Ⅲ shows that the deviation of the observed values measured by hook-intervals is mostly attributable to the difference of the catch rates according to the depth, although some accidental errors can be expected in the observed values. And the diagram of Series Ⅱ reveals that the elemental clusters mostly represented by single isolated individuals or couples of them and indicated by the short periodic deviation of a large amplitude are bundled into rather wide aggregations. But, the following peculiar pattern of the distribution is suggested by the diagram of Series Ⅰ: the population is constituted of many isolated individuals and clusters or aggregations covering from 1 to 3 units (1 ～3 km) and it contains some schools covering about 3 units (3 km) and being spaced by 20 units (20 km) when it is seen as the whole. These schools seem to indicate the blocks of higher catch rate located around the 50th, 150th, 250th and 350th baskets. Besides, the existence of a wider school being 30 units (30 km) apart from these schools is alluded to, although it is

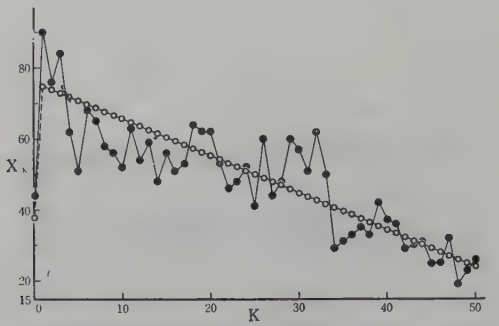


Fig. 12—32(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 32 in the Fishing Ground No. 2).

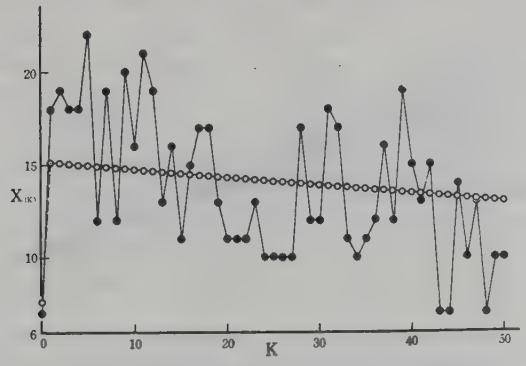


Fig. 12—32(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 32 in the Fishing Ground No.2).

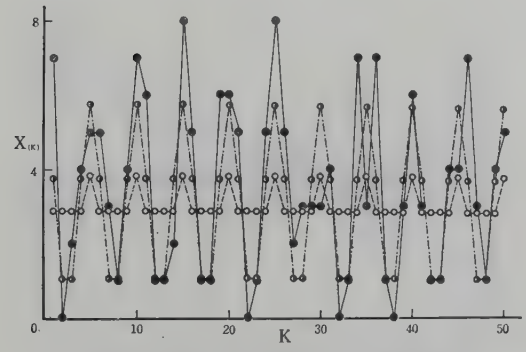


Fig. 12—32(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 32 in the Fishing Ground No.2).

quite uncertain to which part this school is corresponding. Rather, this phenomenon is considered to be caused by the following fact. There is seen a rather continuous distribution covering the range from about the 50th to the 150th basket and another continuous distribution of individuals is observable after the interruption of the width of several consecutive units, in which individuals are arranged so as to keep the distance of *ca.* 30 units (30 km) from respective corresponding individuals in the former school. Accordingly the above-mentioned pattern can be expressed as follows: the population seems to contain two schools in which individuals show rather self-spacing distribution, one of them is located in the range from the 50th to the 150th, while the other in the range from the 200th to the 350th basket.

Example A 33 : It is impossible to develope any consideration upon the diagram of Series Ⅰ, because both the observed and estimated values are very low on account of the scarcity of the caught individuals. The extremely low observed value at $k = 0$

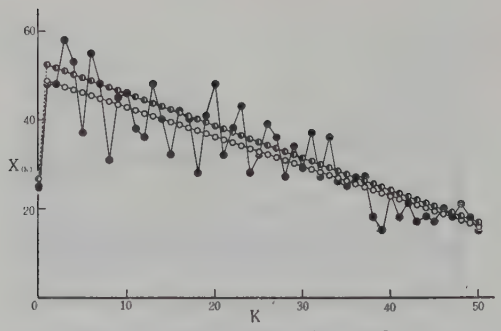


Fig. 12—33(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 33 in the Fishing Ground No.2).

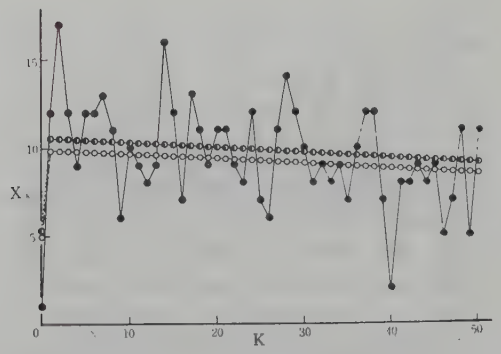


Fig. 12—33(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 33 in the Fishing Ground No.2).

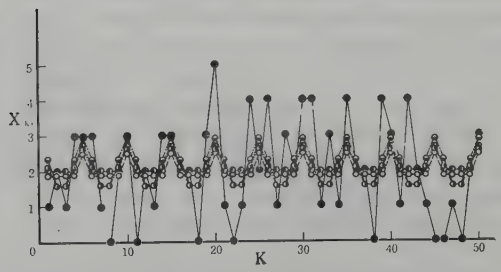


Fig. 12—33(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 33 in the Fishing Ground No.2).

in the diagram of Series Ⅱ seems to indicate that the density of individuals in occupied baskets is lower than in the chance distribution, in other words, individuals are scattered more evenly than distributed by chance. Such occupied baskets are, however, by no means distributed by chance, but they are frequently found in couples being spaced by 2,14 and 28 baskets (0.4, 2.8 and 5.6 km). The diagram of Series Ⅰ suggests the existence of many schools covering 1 or 2 units (1 or 2 km) in the population which is so scattered that the distribution of individuals caught within 3 consecutive units (3 km) next to respective occupied ones is rather regarded as self-spacing. Most of schools mentioned above are constituted of merely 2 individuals and even the largest ones contain less than 6 individuals.

Example A 34 : The low individual density makes it impossible to discuss upon the diagram of Series Ⅲ, though the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 6～7 hooks (240～280 m), 3 (600 m) and 8

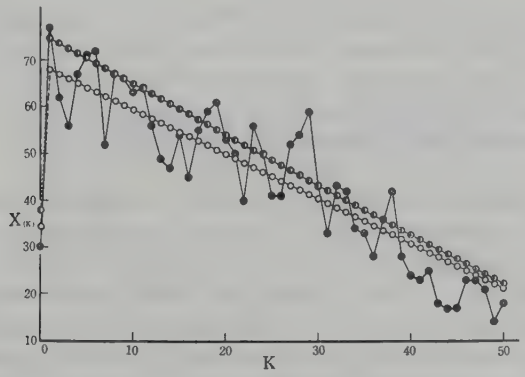


Fig. 12—34(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 34 in the Fishing Ground No.2).

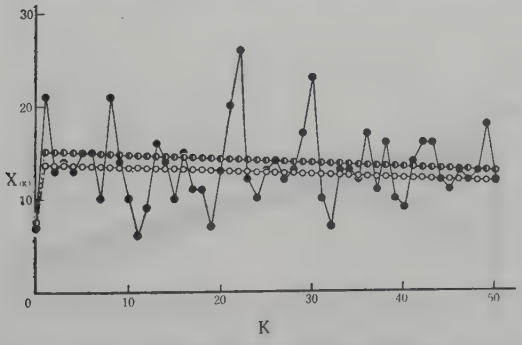


Fig. 12—34(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 34 in the Fishing Ground No.2).

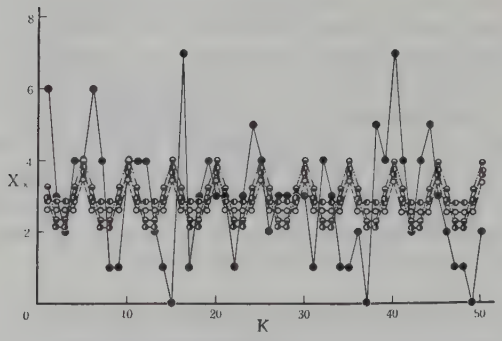


Fig. 12—34(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 34 in the Fishing Ground No.2).

baskets (1.6 km) seem to predominate over others. And the diagram of Series Ⅱ indicates that the couples of occupied baskets spaced by 1, 8, 22 and 30 baskets (0.2, 1.6, 4.4 and 6 km) are predominant. Mingled with this self-spacing population, there are found remarkable schools covering from 1 to 3 units (1～3 km), most of which are, however, constituted of less than several individuals.

Example A 35 : The diagram of Series Ⅲ shows that, besides single isolated individuals, couples of individuals caught side by side (spaced by 40 m), at the hooks spaced by 1, 2, 7 and 8 baskets (0.2, 0.4, 1.4 and 1.6 km) occur frequently than expected. The diagram of Series Ⅱ shows that besides single isolated individuals, there are clusters covering 2 baskets (0.4 km) and that the clusters or individuals are most frequently spaced by 7, 13, 21, 30, 42 and 50 baskets (1.4, 2.6, 4.2, 6.0, 8.4 and 10.0 km), namely roughly at intervals of 7 baskets (1.4 km). Among the population consisting of individuals or clusters distributed at intervals of 2 units (2 km) and several aggregations of 3-unit width (3 km) being constituted of less

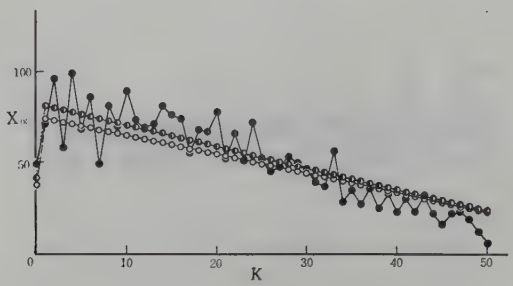


Fig. 12—35(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 35 in the Fishing Ground No.2).

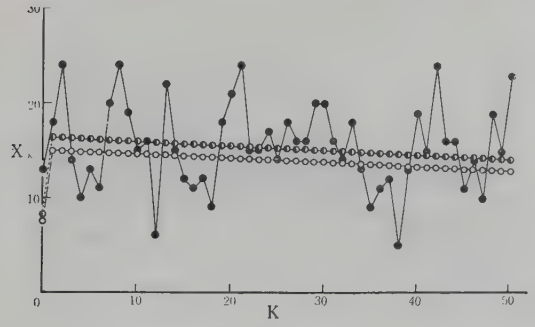


Fig. 12—35(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 35 in the Fishing Ground No.2).

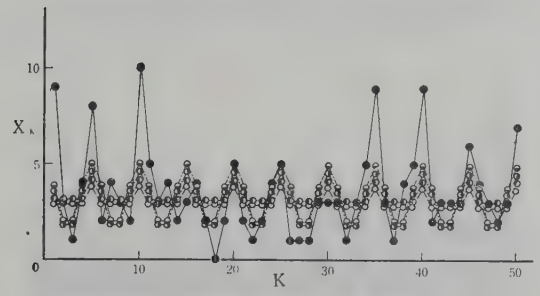


Fig. 12—35(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 35 in the Fishing Ground No.2).

than several individuals, a school covering *ca.* 30 units (30 km) and indicating the parts extending from the 100th to the 250th basket is obscurely discernible.

Example A 36 : Despite of both the low observed and estimated values, it is sug-

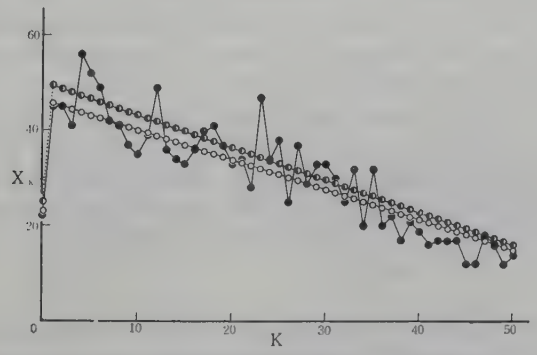


Fig. 12—36(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 36 in the Fishing Ground No.2).

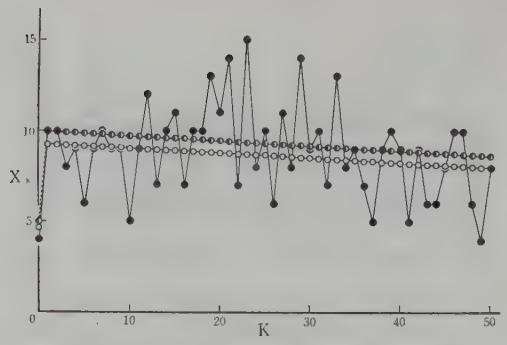


Fig. 12—36(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 36 in the Fishing Ground No.2).

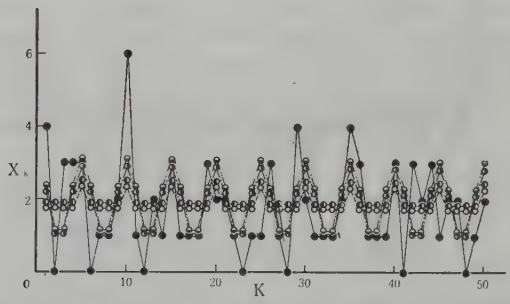


Fig. 12—36(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 36 in the Fishing Ground No.2).

gested from the diagram of Series Ⅲ that the number of individuals caught at successive hooks (spaced by 40 m) or at the hooks spaced by 3 hooks (120 m), 2,6～7 or 8～9 baskets (0.4, 1.2 ～1.4 or 1.6～1.8 km) are more abundant than those in the chance distribution. The diagram of Series Ⅱ shows that the density of individuals within the 10 consecutive baskets (2 km) next to respective occupied ones is lower, while that within the range from 12 to 23 baskets (2.4～4.6 km) is higher than in the chance distribution. The diagram of Series Ⅰ illustrates that the population is so scattered that the number of individuals caught within the 4 successive units (4 km) next to respective occupied ones is less than that in the chance distribution, but it contains many aggregations covering from 1 to 3 units (1～3 km) and being constituted of only a few individuals.

Example A 37 : The diagram of Series Ⅲ illustrates that the single isolated individuals, the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 basket (0.2 km), 9 hooks (360 m), 5 or 10 baskets (1 or 2 km)

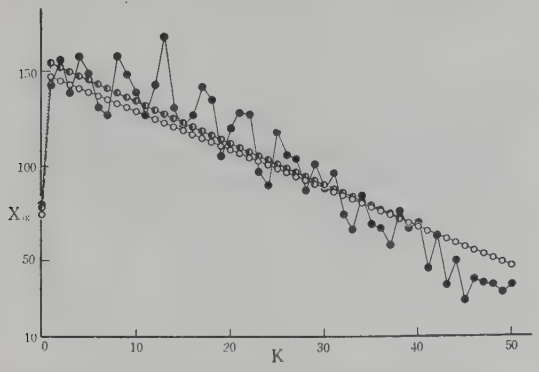


Fig. 12—37(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 37 in the Fishing Ground No.2).

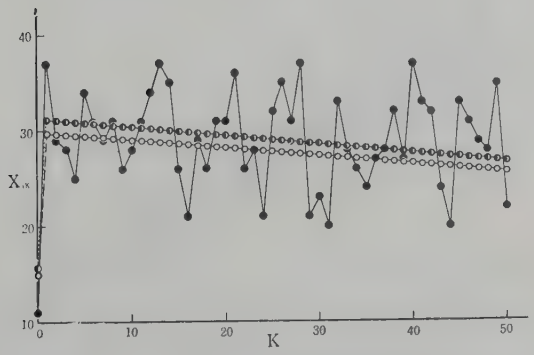


Fig. 12—37(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 37 in the Fishing Ground No.2).

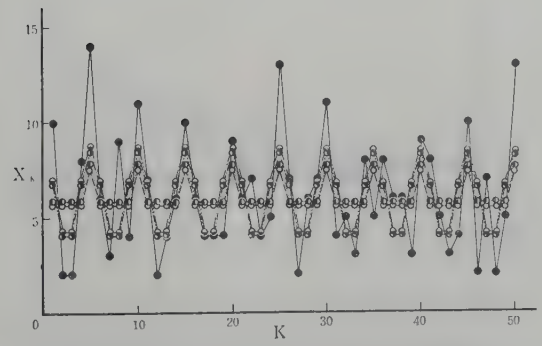


Fig. 12—37(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 37 in the Fishing Ground No.2).

are observable more frequently than those in the chance distribution. And the diagram of Series Ⅱ shows that the number of individuals caught in the baskets spaced by 1, 5, about 12, 21, 27, 32, about 45 and 49 baskets (0.2, 1.0, *ca.* 2.4, 4.2, 5.4, 6.4, *ca.* 9.0 and 9.8 km) from respective occupied ones is more abundant than expected. The presence of a school of negligible weakness covering about 30 units (30 km) is alluded to in the diagram of Series Ⅰ, and this is regarded as a loose bundle of many subordinate aggregations covering from 1 to 3 units (1～3 km) and its situation is supposed to be in the range from the 150th to the 300th basket. The situation of these subordinate aggregations can be assumed in Fig. 11. The existence of other aggregations of the same order outside this school is suggested in the same diagram, and these are considered to indicate the parts of higher catch rates observed around the 100th and 350th baskets.

Example A 38: As for the diagram of Series Ⅱ, no detailed consideration can be

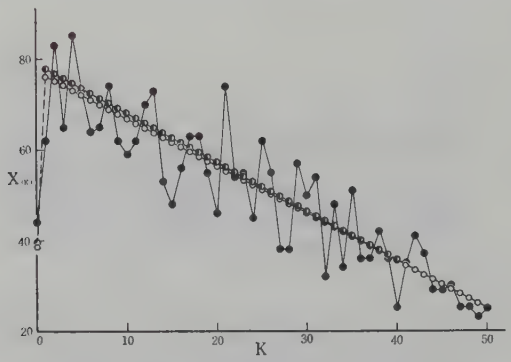


Fig. 12—38(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 38 in the Fishing Ground No. 2).

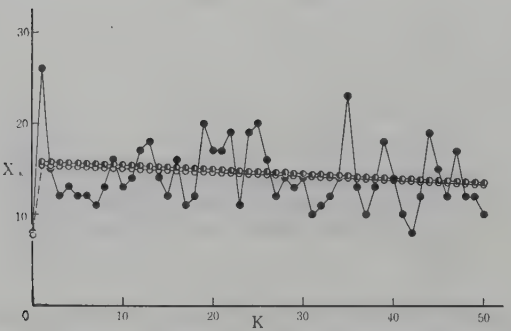


Fig. 12—38(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 38 in the Fishing Ground No. 2).

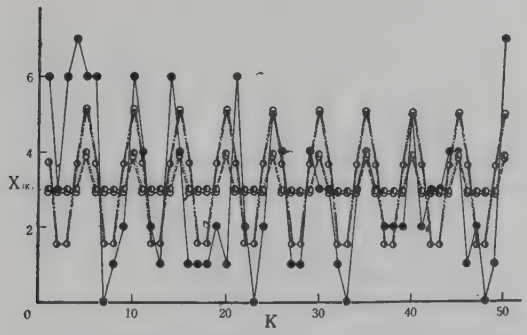


Fig. 12—38(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 38 in the Fishing Ground No.2).

made, because both the observed and estimated values are very low, although it shows obscurely that the number of couples of individuals caught at the hooks spaced by 1～6, 14, 21 or 50 hook-intervals (40～240, 560, 840 or 1,000 m) is more abundant than those in the chance distribution. And the diagram of Series Ⅱ indicates that occupied baskets spaced by from 20 to 25, 35, about 40 and 45 baskets (4～5, 7, *ca.* 8 and 9 km) are observable more frequently than those in the chance distribution. While the diagram of Series Ⅰ shows clearly that many aggregations constituted of less than 10 individuals and covering from 1 to 3 units (1～3 km) are distributed by chance throughout the row of gears.

Example A 39 : Although the scarcity of the observed values makes it very hard to give any explanation about the distribution pattern on the diagram of Series Ⅲ, it seems fairly possible that the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 11, 14, 35, 44 and 45 hook-intervals (440, 560, 1,400, 1,760 and 1,800 m) are observed more abundant than those in the chance distribution. The

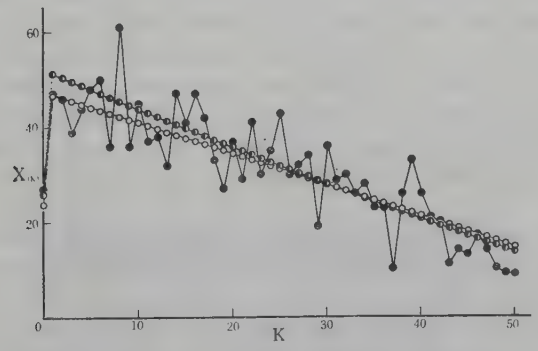


Fig. 12—39(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 39 in the Fishing Ground No.2).

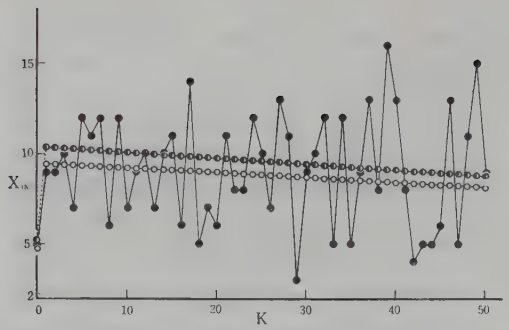


Fig. 12—39(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 39 in the Fishing Ground No.2).

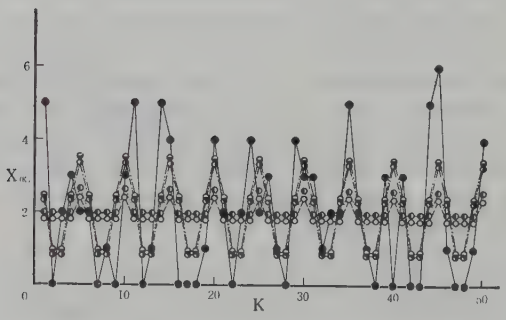


Fig. 12—39(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 39 in the Fishing Ground No.2).

diagram of Series Ⅱ suggests that the population seems to be composed of many clusters covering 1 or 2 baskets (0.2 or 0.4 km) and mostly representing single isolated individuals, even the largest ones of these clusters are constituted of only 3 individuals or thereabout. The distribution pattern and feature of the aggregations covering from 1 to 3 units (1～3 km) and respectively represented by a single or bundle of the above-mentioned clusters which include single isolated individuals and clusters constituted of not so many individuals, are shown as a self-spacing portion extending from 5 to 7 units (5～7 km) in the diagram of Series Ⅰ.

Example A 40 : Despite of the scarcity of caught individuals, the diagram of Series Ⅱ seems to show that single isolated individuals and couples of individuals caught at the hooks spaced by about 1, 6, 7, 8, baskets (0.2, 1.2, 1.4, 1.6 km) or 4～5 baskets (0.8～1.0 km) are frequently observed. The existence of a conspicuous school covering *ca.* 15 units (15 km) is certified by the diagram of Series Ⅰ and this school is considered to be located in the range roughly from the 250th to 300th

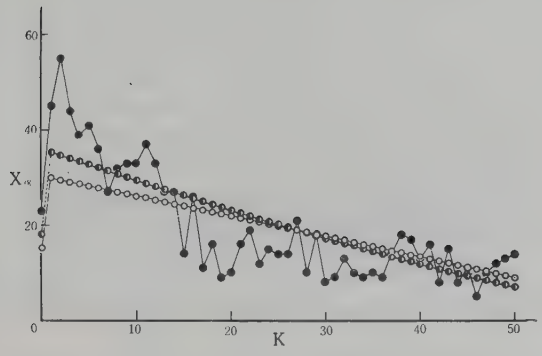


Fig. 12—40(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 40 in the Fishing Ground No. 2).

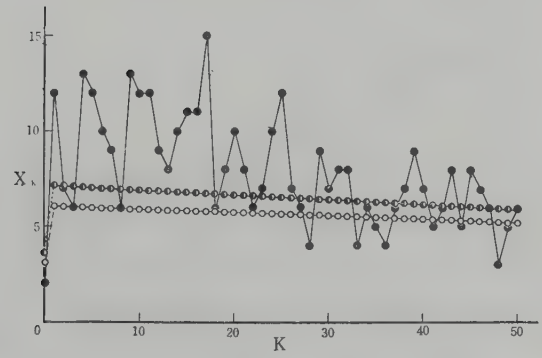


Fig. 12—40(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 40 in the Fishing Ground No. 2).

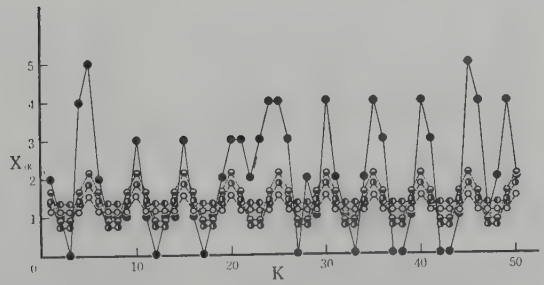


Fig. 12—40(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 40 in the Fishing Ground No. 2).

basket. Although the individuals caught outside this school are rather few, the existence of other 3 small schools, centers of which are respectively *ca.* 30, 40 and 50 units (30, 40 and 50 km) apart from that of the above-mentioned school, is alluded to. Probably they indicate respectively small scattering clusters situated about the 5th, 50th and 150th baskets. The diagram of Series Ⅱ represents the subordinate structure, but here only the structure of the first single school is shown distinctly, because the number of individuals forming the latter 3 schools is far little as comparing with that forming the first one; this school seems to be composed of several rather conspicuous subordinate aggregations covering from 2 to 4 baskets (0.4~0.8 km).

Example A 41 : The low catch rate and the self-spacing distribution result in the scarcity of the observed number, and this makes it hard to deduce out any suggestions

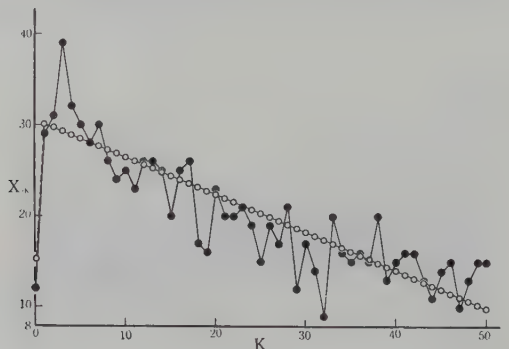


Fig. 12—41(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 41 in the Fishing Ground No. 2).

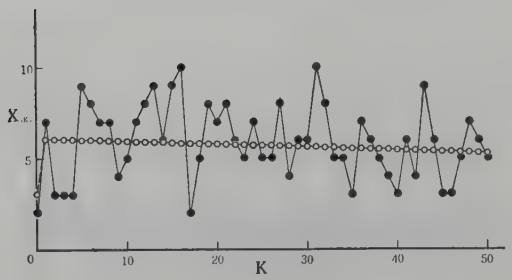


Fig. 12—41(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 41 in the Fishing Ground No. 2).

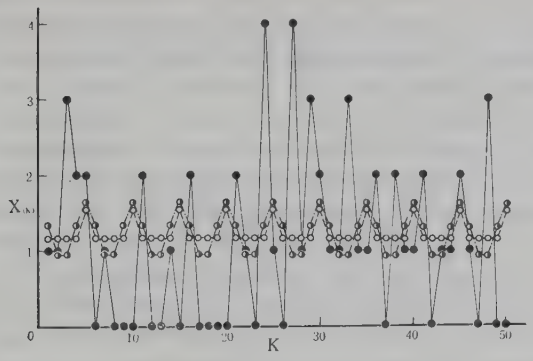


Fig. 12—41(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 41 in the Fishing Ground No. 2).

about the structure of the population from the diagram of Series Ⅲ. The diagram of Series Ⅱ suggests that the number of individuals caught within 3 consecutive baskets (0.6 km) next to respective occupied ones is successively low, but those caught in the range from 5 to 16, around 20, 30 and 43 baskets (1.0~3.2, *ca.* 4, 6 and 8.6 km) are more abundant than those in the chance distribution. In the population, in which the individuals are distributed in a rather self-spacing manner, further the existence of a rather conspicuous school covering 7 units (7 km) and in which the individuals are also distributed in a self-spacing manner is certified. This school seems to be located around the 350th basket. Being apart from this by the distance from 34 to 50 units (34~50 km), several more schools are discernible, they are not so large and considered to indicate the consecutive units of higher catch rate located respectively around the 100th, 150th and 175th baskets and perhaps around the 80th basket, too.

Comparison of the distribution patterns among the 3 species of tuna

The difference or the similarity of the distribution pattern among the above-mentioned 3 species of tuna might be considered to be one of the most important subjects of this article. Actually, however, no essential difference was found in the distribution pattern and hence only a few lines are spared to explain on this subject as follows.

In a word, individuals of these 3 species of tuna —— big-eye tuna, yellow-fin tuna and albacore —— are distributed nearly by chance along the row of gears. But, the data examined more in detail, it becomes clear that the proportion of examples, in which the existence of any contagious schools covering a considerable width, though they are of the negligible weakness, to the whole examples is almost constant throughout the three species, namely the existence of such schools is discernible in a half of the whole examples in each species. On the other hand, the self-spacing pattern is alluded to in about one sixth of examples of big-eye tuna and one third of examples of

albacore, while in examples of yellow-fin tuna, the number of examples showing the self-spacing pattern is rather uncertain, because the catch rate was very low, consequently the observed values are also low, while the deviation of them is large and moreover much accidental errors are expected. However, the relative situation of occupied hooks within a short range —— several hook-intervals —— seems to be somewhat specific. Namely, the extremely strong contagiousness of the catch is observable in successive hooks (40 m) in nearly all examples of big-eye tuna, but the degree of the contagiousness is not so strong in the case of yellow-fin tuna; and such a pattern is quite indiscernible the examples of albacore. Moreover, the width of hook-intervals, where the observed values keep continuously the predominance over the corresponding theoretically estimated ones is rather large in yellow-fin tuna, but it is not so large in big-eye tuna. In albacore, the distribution pattern within such a range does not differ much from the chance distribution.

Consideration upon the Spatial Correlation Between respectively Yellow-fin Tuna and Big-eye Tuna, Tunas and Marlins and Tunas and Sharks

In the preceding chapter, the spatial relation among the individuals of the same species was discussed. It is a well known fact that the geographical distribution of the yellow-fin tuna is seen in the district of the lower latitudes, then comes that of the big-eye tuna and the albacore is distributed in the region of the higher latitudes among these 3 species of tuna. But actually when the catch composition of a row of gears is examined, there occur usually a few of the two species other than the predominant species in the district being mingled with many individuals of the latter, and here arises a question, whether the individuals of such a subordinate species are forming the common school together with the predominant ones, as generally understood, or they are distributed quite independently of or rather repulsively against the latter. On the other hand, it is also a well known fact that sharks and marlins are often caught together with tunas by the same row of gears and they are situated in a little higher food ranks than tunas; therefore, it is very probable that the distributions of tunas and sharks or marlins are interfering one another. Thus, the spatial relation between the individuals of the different species is worthy to be discussed fully as well as that among the individuals of the same species, because it is not only indispensable for considering upon errors, which might be brought into the spatial relation among the individuals of the same species by that the hooks are occupied by other species, but also it is very interesting from the ecological and practical point of view.

1. Construction of the formulae representing the expected number of the couples of individuals, respectively belonging to different species and spaced by k intervals

1) The formulae representing the expected number of the couples of individuals, respectively belonging to different species and spaced by k section-intervals under the supposition that both species are distributed independently of each other

Hereafter, the word "expected number" will be used for indicating the expected number of the couples of individuals, respectively belonging to different species and spaced by k intervals.

Let us set N_A individuals of Species A and N_B of Species B are distributed independently of each other, concerning both individuals and species, along M sections of gears. The probability of occurrence of each individual of each species in each section is $\frac{1}{M}$. Then, the probability of occurrence of a couple of individuals in a certain section is $\left(\frac{1}{M}\right)^2$. There are M sections under consideration and the number of combination to take one individual from Species A and the other from Species B is $N_A N_B$. Accordingly expected number, $C_{(0)}$, is represented as:

$$C_{(0)} = \frac{1}{M^2} M \ N_A N_B = \frac{N_A N_B}{M} \quad \cdots\cdots (31)$$

But, the probability of occurrence of each individual of each species in the ith or the $(i+k)th$ section is $\frac{2}{M}$ and that of any two individuals in the two sections is $\frac{4}{M^2}$: but in the latter case, the probability of both individuals being caught in the same section is included and it is $\frac{1}{M^2}$ for each section. Thus, the probability of any two individuals being caught in separated sections is $\frac{4}{M^2} - 2\frac{1}{M^2} = \frac{2}{M^2}$, in which i varies from 0 to $(M-k)$, and the number of combinations to take one individual from Species A and the other from Species B is $N_A N_B$. Accordingly, the expected number at $k \neq 0$ is represented as:

$$C_{(k)} = \frac{2(M-k) N_A N_B}{M^2} \quad \cdots\cdots (32)$$

On the other hand, the expected number of the couples being constituted of Species A and B may be represented by (expected number of the couples being constituted of Species A and B) —— (that of the couples being constituted of Species A only) —— (that of the couples being constituted of Species B only). That is to say: at $k = 0$

$$C_{(0)} = \frac{(N_A+N_B)(N_A+N_B-1)}{2M} - \frac{N_A(N_A-1)}{2M} - \frac{N_B(N_B-1)}{2M} = \frac{2N_A N_B}{2M}$$

$$= \frac{N_A \ N_B}{M}$$

while at $k \neq 0$

$$C_{(k)}=\frac{(M-k)(N_A+N_B)(N_A+N_B-1)}{M^2}-\frac{(M-k)N_A(N_A-1)}{M^2}$$
$$-\frac{(M-k)N_B(N_B-1)}{M^2}=\frac{2(M-k)N_AN_B}{M^2}$$

Thus, the two groups of formulae representing the expected number and obtained in different procedures, mentioned above, quite coincide with each other.

2) The formulae representing the expected number of the couples of individuals spaced by *k* section-intervals, when the catch rate of each species shows gradient, but both species are distributed independently of each other

Let us set that N_A individuals of Species A and N_B individuals of Species B are distributed along a row of gears constituted of M sections and the number of individuals caught in the *ith* section is represented as $(A_0+i\Delta A)$ for Species A and $(B_0+i\Delta B)$ for Species B. Here, $N_A=\sum_{i=1}^{M}(A_0+i\Delta A)$ and $N_B=\sum_{i=1}^{M}(B_0+i\Delta B)$. Through the same process which was shown in the case when the formulae (31) and (32) were constructed, the formulae representing the expected number are given as follows:

at $k=0$

$$C_{(0)}=\sum_{i=1}^{M}(A_0+i\Delta A)(B_0+i\Delta B)$$
$$=\sum_{i=1}^{M}\{A_0B_0+(A_0\Delta B+B_0\Delta A)i+\Delta A\Delta Bi^2\}$$
$$=A_0B_0\left[M+\frac{M(M+1)}{2}(\delta_A+\delta_B)+M(M+1)(2M+1)\frac{\delta_A\delta_B}{6}\right]$$
$$=A_0B_0M\left[1+(M+1)\frac{\delta_A+\delta_B}{2}+(M+1)(2M+1)\frac{\delta_A\delta_B}{6}\right] \cdots\cdots (33)$$

here $\delta_A=\frac{\Delta A}{A_0}$ and $\delta_B=\frac{\Delta B}{B_0}$,

while at $k \neq 0$

$$C_{(k)}=\sum_{i=1}^{M-k}(A_0+i\Delta A)(B_0+\overline{i+k}\Delta B)+\sum_{i=1}^{M-k}(B_0+i\Delta B)(A_0+\overline{i+k}\Delta A)$$
$$=A_0B_0(M-k)\left[2+(M+1)(\delta_A+\delta_B)+(M-k+1)(2M+k+1)\frac{\delta_A\delta_B}{3}\right] \cdots (34)$$

On the other hand, $C_{(0)}$ and $C_{(k)}$ are also obtained by the same procedure as the second constructing method of formulae (31) and (32); that is to say,

at $k=0$

$$C_{(0)}=\frac{1}{2}\sum_{i=1}^{M}\left\{(A_0+i\Delta A)+(B_0+i\Delta B)\right\}\left\{(A_0+i\Delta A)+(B_0+i\Delta B)-1\right\}$$

$$-\frac{1}{2}\sum_{i=1}^{M}(A_0+i\Delta A)(A_0+i\Delta A-1)-\frac{1}{2}\sum_{i=1}^{M}(B_0+i\Delta B)(B_0+i\Delta B-1)$$

$$=\sum_{i=1}^{M}(A_0+i\Delta A)(B_0+i\Delta B)$$

while at $k \neq 0$

$$C_{(k)}=\sum_{i=1}^{M-k}\left\{(A_0+i\Delta A)+(B_0+i\Delta B)\right\}\left\{(A_0+\overline{i+k}\Delta A)+(B_0+\overline{i+k}\Delta B)\right\}$$

$$-\sum_{i=1}^{M-k}(A_0+i\Delta A)(A_0+\overline{i+k}\Delta A)-\sum_{i=1}^{M-k}(B_0+i\Delta B)(B_0+\overline{i+k}\Delta B)$$

$$=\sum_{i=1}^{M-k}(A_0+i\Delta A)(B_0+\overline{i+k}\Delta B)+\sum_{i=1}^{M-k}(B_0+i\Delta B)(A_0+\overline{i+k}\Delta A)$$

3) The formulae representing the expected number of the couples of individuals spaced by *k* hook-intervals, when individuals of both species are distributed independently of each other

Let us set that N_A individuals of Species A and N_B individuals of Species B are distributed independently of each other, and there are m baskets in a row. The probability of occurrence of an individual at a hook is $P_A=\frac{N_A}{Hm}$ for Species A and $P_B=\frac{N_B}{Hm}$ for Species B. The hooks spaced by k hook-intervals from respective hooks in the ith basket are illustrated in Tables 4 and 7. Thus when $R=0$, there are H hooks in the $(i+a)th$ basket, which are spaced by k hook-intervals from respective hooks in the ith basket, while there is no hook in the $(i+a+1)th$ basket. But when $R \neq 0$ there are $(H-R)$ hooks in the $(i+a)th$ basket, which are spaced by k hook-intervals from respective hooks in the ith basket and there are still $(R-1)$ hooks in the $(i+a+1)th$ basket. Here, concerning the couples consisting of a hook in the ith basket and that in the $(i+a)th$ basket, i can vary from 0 to $(m-a)$, while for the couples composed of a hook in the ith basket and that in the $(i+a+1)th$ basket, i can vary from 0 to $(m-a-1)$. The expected number of the case in which an individual of Species A is caught at a hook in the ith basket and an individual of Species B at a hook in the $(i+a)th$ or the $(i+a+1)th$ basket is: ——

$C_{(k)1}=H(m-a)P_AP_B$ (at $R=0$)

$C_{(k)1}=\{(H-R)(m-a)+(R-1)(m-a-1)\}P_AP_B$ (at $R \neq 0$)

Here, k is represented as $k=a(H+1)+R$ by the same way as that used to construct formulae (6) and (7). While, expected number of one individual of Species B is caught at a hook in the ith basket and one individual of Species A at a hook in the $(i+a)th$ or the $(i+a+1)th$ basket is also,

$C_{(k)2}=H(m-a)P_BP_A$ (at $R=0$)

$C_{(k)_2}=\{(H-R)(m-a)+(R-1)(m-a-1)\}P_BP_A$ (at $R\neq 0$)

Accordingly, the expected number, $C_{(k)}$, which is equal to $C_{(k)_1}+C_{(k)_2}$ is represented as follows:

at $R=0$ $C_{(k)}=2H(m-a)P_AP_B$ ..... (35)

while at $R\neq 0$ $C_{(k)}=2\{(H-R)(m-a)+(R-1)(m-a-1)\}P_AP_B$ ..... (36)

On the other hand, by the same manner as the second method to construct formulae (31) and (32), the formulae representing the expected number which is equal to (expected number of the couples being constituted of Species A and B) —— (that of the couples being constituted of Species A only) —— (that of the couples being constituted of Species B only) are constructed as follows:

at $R=0$

$$C_{(k)}=H(m-a)\{(P_A+P_B)^2-P_A^2-P_B^2\}$$
$$=2H(m-a)P_AP_B$$

while at $R\neq 0$

$$C_{(k)}=\{(H-R)(m-a)+(R-1)(m-a-1)\}\{(P_A+P_B)^2-P_A^2-P_B^2\}$$
$$=2\{(H-R)(m-a)+(R-1)(m-a-1)\}P_AP_B$$

4) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when both species are distributed keeping some gradients

Let us set that k is represented as $k=a(H+1)+R$, being separated into the part divisible by a basket length and the remainder (R), and there are m baskets in a row. Represent the individual numbers of Species A or B being caught at one hook in the ith, $(i+a)th$ and $(i+a+1)th$ baskets as $(A_0+i\Delta A)$, $(A_0+\overline{i+a}\Delta A)$ and $(A_0+i+a+1\,\Delta A)$ or $(B_0+i\Delta B)$, $(B_0+i+a\Delta B)$ and $(B_0+i+\overline{a+1}\,\Delta B)$ respectively, and the expected number of two hooks spaced by k hook-intervals being occupied as that one of them is occupied by an individual of Species A, while the other by an individual of Species B, $C_{(k)}$, can be estimated by the following formulae:

at $R=0$

$$C_{(k)}=H\sum_{i=1}^{m-a}\left\{(A_0+i\Delta A)(B_0+\overline{i+a}\Delta B)+(B_0+i\Delta B)(A_0+\overline{i+a}\Delta A)\right\}$$
$$=A_0B_0H(m-a)\left[2+(m+1)(\delta_A+\delta_B)+(m-a+1)(2m+a+1)\frac{\delta_A\delta_B}{3}\right]\cdots(37)$$

while at $R\neq 0$

$$C_{(k)}=(H-R)\sum_{i=1}^{m-a}\left\{(A_0+i\Delta A)(B_0+\overline{i+a}\Delta B)+(B_0+i\Delta B)(A_0+\overline{i+a}\Delta A)\right\}$$
$$+(R-1)\sum_{i=1}^{m-a-1}\left\{(A_0+i\Delta A)(B_0+\overline{i+a+1}\,\Delta B)+(B_0+i\Delta B)(A_0+\overline{i+a+1}\,\Delta A)\right\}$$
$$=(H-R)A_0B_0(m-a)\left[2+(m+1)(\delta_A+\delta_B)+(m-a+1)(2m+a+1)\frac{\delta_A\delta_B}{3}\right]$$

$$+(R-1)A_0B_0(m-a-1)\left[2+(m+1)(\delta_A+\delta_B)\right.$$

$$\left.+(m-a)(2m+a+2)\frac{\delta_A\delta_B}{3}\right] \quad \cdots\cdots(38)$$

here $\delta_A=\frac{\Delta A}{A_0}$ and $\delta_B=\frac{\Delta B}{B_0}$.

On the other hand, quite the same formulae can be obtained by (expected number of the couples being constituted of Species A and B) —— (that of the couples being constituted of Species A only) —— (that of the couples being constituted of Species B only). That is to say:

at $R=0$

$$C_{(k)}=H\sum_{i=1}^{m-a}\left[\left\{(A_0+i\Delta A)+(B_0+i\Delta B)\right\}\left\{(A_0+\overline{i+a}\Delta A)+(B_0+\overline{i+a}\Delta B)\right\}\right.$$

$$\left.-(A_0+i\Delta A)(A_0+\overline{i+a}\Delta A)-(B_0+i\Delta B)(B_0+\overline{i+a}\Delta B)\right]$$

$$=H\sum_{i=1}^{m-a}\left\{(A_0+i\Delta A)(B_0+\overline{i+a}\Delta B)+(B_0+i\Delta B)(A_0+\overline{i+a}\Delta A)\right\}$$

while at $R\neq 0$

$$C_{(k)}=(H-R)\sum_{i=1}^{m-a}\left[\left\{(A_0+i\Delta A)+(B_0+i\Delta B)\right\}\left\{(A_0+i+a\Delta A)+(B_0+i+a\Delta B)\right\}\right.$$

$$\left.-(A_0+i\Delta A)(A_0+\overline{i+a}\Delta A)-(B_0+i\Delta B)(B_0+\overline{i+a}\Delta B)\right]$$

$$+(R-1)\sum_{i=1}^{m-a-1}\left[\left\{(A_0+i\Delta A)+(B_0+i\Delta B)\right\}\left\{(A_0+\overline{i+a+1}\Delta A)\right.\right.$$

$$\left.\left.+(B_0+\overline{i+a+1}\Delta B)\right\}-(A_0+i\Delta A)(A_0+\overline{i+a+1}\Delta A)\right.$$

$$\left.-(B_0+i\Delta B)(B_0+\overline{i+a+1}\Delta B)\right]$$

5) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when the catch rate differs according to depth in both species

Let us set that N_{A1} and N_{A2} individuals of Species A are caught respectively at the hooks arranged in two, shallower and deeper, depth levels along the row of gears being constituted of m baskets each having 4 hooks and N_{B1} and N_{B2} individuals of Species B are caught in the same manner as in Species A. The probabilities of occurrence of individuals of Species A or B at the shallower and deeper hooks are $P_{A1}=\frac{N_{A1}}{2m}$ and $P_{A2}=\frac{N_{A2}}{2m}$ or $P_{B1}=\frac{N_{B1}}{2m}$ and $P_{B2}=\frac{N_{B2}}{2m}$ respectively. Repre-

sent $k=a(H+1)+R$ by the same way as that shown in the previous sections, and the hooks spaced by k hook-intervals from respective hooks in the ith basket are represented in Table 4. And the formulae representing the expected number of two hooks being occupied as that one of them is occupied by an individual of Species A and the other by Species B is illustrated as follows:

at $R=0$ $C_{(k)}=2(m-a)(2P_{A_1}P_{B_1}+2P_{A_2}P_{B_2})$ ..... (39)

$R=1$ $C_{(k)}=2(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2})$ ..... (40)

$R=2$ $C_{(k)}=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-P_{A_1}P_{B_1}]$ ..... (41)

$R=3$ $C_{(k)}=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-(P_{A_1}P_{B_2}+P_{A_2}P_{B_1})]$ ..... (42)

$R=4$ $C_{(k)}=2(m-a-1)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2})$ ..... (43)

On the other hand, they can be estimated by subtracting (expected number of the couples being constituted of Species A only) and (expected number of the couples being constituted of Species B only) from (expected number of the couples being constituted of Species A and B), and the process of this construction is shown below.

at $R=0$

$$\begin{aligned}C_{(k)}&=(m-a)[\{2(P_{A_1}+P_{B_1})^2+2(P_{A_2}+P_{B_2})^2\}-(2P_{A_1}{}^2+2P_{A_2}{}^2)\\&\quad-(2P_{B_1}{}^2+2P_{B_2}{}^2)]\\&=2(m-a)(2P_{A_1}P_{B_1}+2P_{A_2}P_{B_2})\end{aligned}$$

$R=1$

$$\begin{aligned}C_{(k)}&=(m-a)[2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_2}+P_{B_2})^2-(2P_{A_1}P_{A_2}+P_{A_2}{}^2)\\&\quad-(2P_{B_1}P_{B_2}+P_{B_2}{}^2)]\\&=2(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2})\end{aligned}$$

$R=2$

$$\begin{aligned}C_{(k)}&=[(m-a)\{2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_1}+P_{B_1})^2\}-(P_{A_1}+P_{B_1})^2]\\&\quad-[(m-a)(2P_{A_1}P_{A_2}+P_{A_1}{}^2)-P_{A_1}{}^2]-[(m-a)(2P_{B_1}P_{B_2}+P_{B_1}{}^2)-P_{B_1}{}^2]\\&=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-P_{A_1}P_{B_1}]\end{aligned}$$

$R=3$

$$\begin{aligned}C_{(k)}&=[(m-a)\{2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_1}+P_{B_1})^2\}-2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})]\\&\quad-[(m-a)(2P_{A_1}P_{A_2}+P_{A_1}{}^2)-2P_{A_1}P_{A_2}]-[(m-a)(2P_{B_1}P_{B_2}+P_{B_1}{}^2)-2P_{B_1}P_{B_2}]\\&=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-(P_{A_1}P_{B_2}+P_{A_2}P_{B_1})]\end{aligned}$$

$R=4$

$$\begin{aligned}C_{(k)}&=(m-a-1)[2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_2}+P_{B_2})^2]\\&\quad-(m-a-1)[2P_{A_1}P_{A_2}+P_{A_2}{}^2]-(m-a-1)[2P_{B_1}P_{B_2}+P_{B_2}{}^2]\\&=2(m-a-1)[P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2}]\end{aligned}$$

6) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when the catch rate increases with the soaking time and differs according to depth in both species

Let us set that the catch rates of individuals of Species A at shallower and deeper hooks in the ith basket are represented respectively by $(As_0+i\Delta As)$ and $(Ad_0$

$+i\Delta Ad)$, while those of Species B are $(Bs_0+i\Delta Bs)$ and $(Bd_0+i\Delta Bd)$. The expected number of the occurrence of the couples of individuals spaced by k hook-intervals and being constituted of Species A and B is estimated by the following formulae which are each the sum of two formulae, in one of which $(As_0+i\Delta As)$ and $(Ad_0+i\Delta Ad)$ are substituted for $(P_1+i\Delta P_1)$ and $(P_2+i\Delta P_2)$ of formulae (20)$\sim$(24) and $(Bs_0+\overline{i+a}\Delta Bs)$, $(Bs_0+\overline{i+a+1}\Delta Bs)$, $(Bd_0+\overline{i+a}\Delta Bd)$ and $(Bd_0+\overline{i+a+1}\Delta Bd)$ are for $(P_1+\overline{i+a}\Delta P_1)$, $(P_1+\overline{i+a+1}\Delta P_1)$, $(P_2+\overline{i+a}\Delta P_2)$ and $(P_2+\overline{i+a+1}\Delta P_2)$, while in the other $(Bs_0+i\Delta Bs)$ and $(Bd_0+i\Delta Bd)$ are substituted for $(P_1+i\Delta P_1)$ and $(P_2+i\Delta P_2)$ and $(As_0+\overline{i+a}\Delta As)$, $(As_0+\overline{i+a+1}\Delta As)$, $(Ad_0+\overline{i+a}\Delta Ad)$ and $(Ad_0+\overline{i+a+1}\Delta Ad)$ are for $(P_1+\overline{i+a}\Delta P)$, $(P_1+\overline{i+a+1}\Delta P_1)$, $(P_2+\overline{i+a}\Delta P_2)$ and $(P_2+\overline{i+a+1}\Delta P_2)$.

at R = 0

$$C_{(k)}=2\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+2\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a}\Delta Bd)$$
$$+2\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)+2\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a}\Delta Ad)$$
$$=2As_0Bs_0(m-a)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_s}{3}\right]$$
$$+2Ad_0Bd_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_d}{3}\right] \quad \cdots\cdots (44)$$

R = 1

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a}\Delta Ad)$$
$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a}\Delta Ad)$$
$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(As_0+\overline{i+a}\Delta As)$$
$$=As_0Bd_0(m-a)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_d}{3}\right]$$
$$+Ad_0Bs_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_s}{3}\right]$$
$$+Ad_0Bd_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_d}{3}\right] \quad \cdots\cdots (45)$$

R = 2

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a}\Delta Ad)$$

$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(As_0+\overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bs_0+\overline{i+a+1}\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(As_0+\overline{i+a+1}\Delta As)$$

$$=As_0\,Bd_0\,(m-a)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_d}{3}\right]$$

$$+Ad_0\,Bs_0\,(m-a)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_s}{3}\right]$$

$$+As_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_s}{3}\right]$$

.....(46)

R = 3

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+\overline{i+a+1}\Delta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a+1}\Delta Ad)$$

$$=As_0\,Bs_0\,(m-a)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_s}{3}\right]$$

$$+Ad_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_d\,\delta B_s}{3}\right]$$

$$+As_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_d}{3}\right]$$

.....(47)

R = 4

$$C_{(k)}=\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a+1}\,\Delta Bd)$$
$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$
$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+\overline{i+a+1}\,\Delta Bd)$$
$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$
$$=Ad_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_d\,\delta B_s}{3}\right]$$
$$+As_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_d}{3}\right]$$
$$+Ad_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta A_d+\delta B_d)+(m-a)(2m+a+2)\frac{\delta A_d\,\delta B_d}{3}\right]$$
..... (48)

here $\delta A_s=\dfrac{\Delta As}{As_0}$, $\delta A_d=\dfrac{\Delta Ad}{Ad_0}$, $\delta B_s=\dfrac{\Delta Bs}{Bs_0}$ and $\delta B_d=\dfrac{\Delta Bd}{Bd_0}$.

On the other hand, the formulae available for such conditions can be obtained by the same manner as the second method constructing the previously shown formulae representing the correlation and this procedure is shown below.

at $R=0$

$$C_{(k)}=2\sum_{i=1}^{m-a}\left[\left\{(As_0+i\Delta As)+(Bs_0+i\Delta Bs)\right\}\left\{(As_0+i+a\Delta As)+(Bs_0+i+a\Delta Bs)\right\}\right.$$
$$\left.-(As_0+i\Delta As)(As_0+\overline{i+a}\Delta As)-(Bs_0+i\Delta Bs)(Bs_0+\overline{i+a}\Delta Bs)\right]$$
$$+2\sum_{i=1}^{m-a}\left[\left\{(Ad_0+i\Delta Ad)+(Bd_0+i\Delta Bd)\right\}\left\{(Ad_0+i+a\Delta Ad)+(Bd_0+i+a\Delta Bd)\right\}\right.$$
$$\left.-(Ad_0+i\Delta Ad)(Ad_0+\overline{i+a}\Delta Ad)-(Bd_0+i\Delta Bd)(Bd_0+\overline{i+a}\Delta Bd)\right]$$
$$=2\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+i+a\Delta Bs)+2\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+i+a\Delta As)$$
$$+2\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a}\Delta Bd)+2\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a}\Delta Ad)$$

$R=1$

$$C_{(k)}=\sum_{i=1}^{m-a}\left[\left\{(As_0+i\Delta As)+(Bs_0+i\Delta Bs)\right\}\left\{(Ad_0+i+a\Delta Ad)+(Bd_0+i+a\Delta Bd)\right\}\right.$$

$$- (As_0 + i\Delta As)\,(Ad_0 + \overline{i+a}\Delta Ad) - (Bs_0 + i\Delta Bs)\,(Bd_0 + \overline{i+a}\Delta Bd)\Big]$$

$$+ \sum_{i=1}^{m-a}\Big[\Big\{(Ad_0 + i\Delta Ad) + (Bd_0 + i\Delta Bd)\Big\}\Big\{(Ad_0 + i + a\Delta Ad) + (Bd_0 + i + a\Delta Bd)\Big\}$$

$$- (Ad_0 + i\Delta Ad)\,(Ad_0 + \overline{i+a}\Delta Ad) - (Bd_0 + i\Delta Bd)\,(Bd_0 + \overline{i+a}\Delta Bd)\Big]$$

$$+ \sum_{i=1}^{m-a}\Big[\Big\{(Ad_0 + i\Delta Ad) + (Bd_0 + i\Delta Bd)\Big\}\Big\{(As_0 + i + a\Delta As) + (Bs_0 + i + a\Delta Bs)\Big\}$$

$$- (Ad_0 + i\Delta Ad)\,(As_0 + \overline{i+a}\Delta As) - (Bd_0 + i\Delta Bd)\,(Bs_0 + \overline{i+a}\Delta Bs)\Big]$$

$$= \sum_{i=1}^{m-a}(As_0 + i\Delta As)\,(Bd_0 + \overline{i+a}\Delta Bd) + \sum_{i=1}^{m-a}(Bs_0 + i\Delta Bs)\,(Ad_0 + \overline{i+a}\Delta Ad)$$

$$+ \sum_{i=1}^{m-a}(Ad_0 + i\Delta Ad)\,(Bd_0 + \overline{i+a}\Delta Bd) + \sum_{i=1}^{m-a}(Bd_0 + i\Delta Bd)\,(Ad_0 + \overline{i+a}\Delta Ad)$$

$$+ \sum_{i=1}^{m-a}(Ad_0 + i\Delta Ad)\,(Bs_0 + \overline{i+a}\Delta Bs) + \sum_{i=1}^{m-a}(Bd_0 + i\Delta Bd)\,(As_0 + \overline{i+a}\Delta As)$$

R = 2

$$C_{(k)} = \sum_{i=1}^{m-a}\Big[\Big\{(As_0 + i\Delta As) + (Bs_0 + i\Delta Bs)\Big\}\Big\{(Ad_0 + i + a\Delta Ad) + (Bd_0 + \overline{i+a}\Delta Bd)\Big\}$$

$$- (As_0 + i\Delta As)\,(Ad_0 + \overline{i+a}\Delta Ad) - (Bs_0 + i\Delta Bs)\,(Bd_0 + \overline{i+a}\Delta Bd)\Big]$$

$$+ \sum_{i=1}^{m-a}\Big[\Big\{(Ad_0 + i\Delta Ad) + (Bd_0 + i\Delta Bd)\Big\}\Big\{(As_0 + i + a\Delta As) + (Bs_0 + i + a\Delta Bs)\Big\}$$

$$- (Ad_0 + i\Delta Ad)\,(As_0 + \overline{i+a}\Delta As) - (Bd_0 + i\Delta Bd)\,(Bs_0 + \overline{i+a}\Delta Bs)\Big]$$

$$+ \sum_{i=1}^{m-a-1}\Big[\Big\{(As_0 + i\Delta As) + (Bs_0 + i\Delta Bs)\Big\}\Big\{(As_0 + i + a + 1\Delta As) + (Bs_0 + i + a + 1\Delta Bs)\Big\}$$

$$- (As_0 + i\Delta As)\,(As_0 + \overline{i+a+1}\Delta As) - (Bs_0 + i\Delta Bs)\,(Bs_0 + \overline{i+a+1}\Delta Bs)\Big]$$

$$= \sum_{i=1}^{m-a}(As_0 + i\Delta As)\,(Bd_0 + \overline{i+a}\Delta Bd) + \sum_{i=1}^{m-a}(Bs_0 + i\Delta Bs)\,(Ad_0 + \overline{i+a}\Delta Ad)$$

$$+ \sum_{i=1}^{m-a}(Ad_0 + i\Delta Ad)\,(Bs_0 + \overline{i+a}\Delta Bs) + \sum_{i=1}^{m-a}(Bd_0 + i\Delta Bd)\,(As_0 + \overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(As_0+\overline{i+a+1}\,\Delta As)$$

R = 3

$$C_{(k)}=\sum_{i=1}^{m-a}\Big[\Big\{(As_0+i\Delta As)+(Bs_0+i\Delta Bs)\Big\}\Big\{(As_0+i+a\Delta As)+(Bs_0+i+a\Delta Bs)\Big\}$$

$$-(As_0+i\Delta As)(As_0+\overline{i+a}\Delta As)-(Bs_0+i\Delta Bs)(Bs_0+\overline{i+a}\Delta Bs)\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(Ad_0+i\Delta Ad)+(Bd_0+i\Delta Bd)\Big\}\Big\{(As_0+\overline{i+a+1}\,\Delta As)$$

$$+(Bs_0+\overline{i+a+1}\,\Delta Bs)\Big\}-(Ad_0+i\Delta Ad)(As_0+\overline{i+a+1}\,\Delta As)$$

$$-(Bd_0+i\Delta Bd)(Bs_0+\overline{i+a+1}\,\Delta Bs)\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(As_0+i\Delta As)+(Bs_0+i\Delta Bs)\Big\}\Big\{(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$+(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big\}-(As_0+i\Delta As)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$-(Bs_0+i\Delta Bs)(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big]$$

$$=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\,\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+\overline{i+a+1}\,\Delta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

R = 4

$$C_{(k)}=\sum_{i=1}^{m-a-1}\Big[\Big\{(Ad_0+i\Delta Ad)+(Bd_0+i\Delta Bd)\Big\}\Big\{(As_0+\overline{i+a+1}\,\Delta As)$$

$$+(Bs_0+\overline{i+a+1}\,\Delta Bs)\Big\}-(Ad_0+i\Delta Ad)(As_0+\overline{i+a+1}\,\Delta As)$$

$$-(Bd_0+i\Delta Bd)(Bs_0+\overline{i+a+1}\,\Delta Bs)\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(Ad_0+i\Delta Ad)+(Bd_0+i\Delta Bd)\Big\}\Big\{(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$+(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big\}-(Ad_0+i\Delta Ad)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$-(Bd_0+i\Delta Bd)(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(As_0+i\Delta As)+(Bs_0+i\Delta Bs)\Big\}\Big\{(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$+(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big\}-(As_0+i\Delta As)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$-(Bs_0+i\Delta Bs)(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big]$$

$$=\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\,\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a+1}\,\Delta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+\overline{i+a+1}\,\Delta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

2. Analyses of the spatial correlation between individuals of two kind of fishes being distributed along the same row of gears

The above-mentioned formulae show the expected number of the couples of individuals belonging to different species and spaced by k section-intervals or hook-intervals, when

individuals of both species are distributed independently of each other. And the series of the estimated values show the type of change according to the increase of k almost the same as that of the values computed by the formulae given in the preceding chapter. The estimated values of the preceding series, in which the influence of the gradient of the catch rate is taken into consideration, change following a weakly cubic curve and those computed within the range of k from 0 to not so large value are a little higher than those in which the influence of the gradient is not taken into consideration which follow a linear function, while the estimated values computed in the range of k from neither so small to nor so large value are slightly lower irrespective as to whether the catch rate is increasing or decreasing. But the relation between the two series of the estimated values of this analysis —— the influence of the gradient is taken into consideration or not —— is not always the same as the above-mentioned relation. The above-mentioned relation is seen between the two series of the estimated values only when the direction of the gradient is the same in both species, while when the direction of the gradient is opposite to each other in the two species, the relation is reverse, although the series in which the influence of gradient is taken into consideration follows also a weakly cubic curve and the series in which the influence of the gradient is put out of consideration changes along a linear function.

Before going further, it must be noted that the fishing method, long-line, itself is accompanied with a fundamentally unfavourable condition for the analysis of the spatial relation; when the catch rate is high partially or throughout the whole row of gears, the effect of the occupation of a hook by each individual, which naturally makes it impossible that the hook can be occupied by other individuals of the same or other species, becomes somewhat serious, and this results in the fact that the distribution of a single species or both species is misregarded as a little more self-spacing, or even as repulsive than actual, and moreover when each or both species are caught in dense schools and at the same time the unit length adopted in consideration is too short, the matter might occasionally be put into an insoluble confusion. The correlation diagrams were decoded on the basis of such preliminary knowledge.

1) Correlation between big-eye tuna and yellow-fin tuna

At Sts. 1—10 in the Fishing Ground No. 1, a relatively large number of individuals of yellow-fin tuna were caught mingled with big-eye tuna, both of these are commercially very important species. Thus, the spatial correlation between these two species was analyzed as an example. Generally, individuals of these species are distributed almost independently of each other, more exactly, their distributions are rather repulsive.

Exposition of particular example

Example C b–y 1 : This is the example obtained at St. 1 in the Fishing Ground No. 1. The catch of big-eye tuna increases with the soaking time, while that of yellow-fin tuna shows rather a negligibly weak decrease with the soaking time.

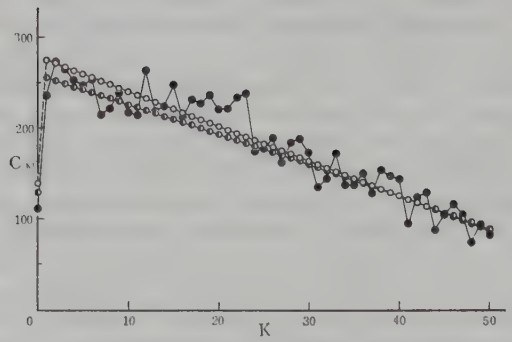


Fig. 13—1 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 1 in the Fishing Ground No. 1).

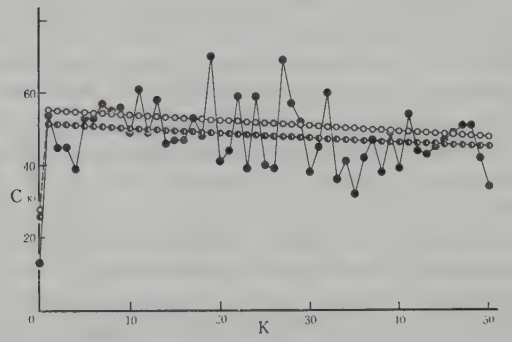


Fig. 13—1 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 1 in the Fishing Ground No. 1).

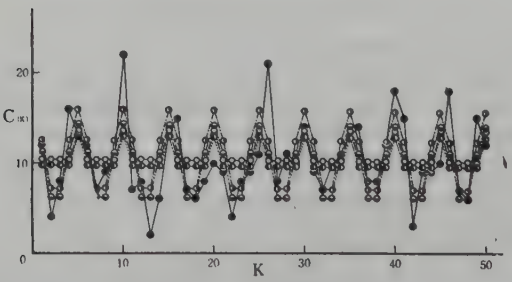


Fig. 13—1 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 1 in the Fishing Ground No. 1).

Accordingly, when k is not so large, the series of the estimated values, in which the influence of the gradient of the catch rate is taken into consideration, shows slightly lower values than in the series in which the influence of it is put out of consideration. And as no large school is detected in both species, it is unnecessary to give any special consideration to the influence of the large school. Even when the influence of the gradients of opposite directions, which might cause the repulsive pattern of the distribution, is taken into consideration, there is shown still a repulsive pattern extending to two units (= 10 baskets ≒ 2 km) in the diagram of Series Ⅰ, in which the theoretical values are computed by formulae (31) ~ (34) taking 5 consecutive baskets (≒*ca.* 1 km) as a unit. The diagram of Series Ⅱ, in which the estimated values are computed from formulae (31) ~ (34) shortening the unit length in consideration to 1 basket (≒ *ca.* 200 m), indicates nothing else than the feature shown in the diagram of Series Ⅰ, although it shows some deviation within the unit adopted in the Series Ⅰ (= 5 baskets). The diagram of Series Ⅲ shows the individuals of yellow-fin tuna caught at the hooks spaced by 10 or 26 hook-intervals (0.4 or *ca.* 1 km) from respective hooks occupied by big-eye tuna are more abundant than those in the independent distribution and that so strong repulsion cannot be observed within a short range between the individuals of yellow-fin tuna and big-eye tuna, although the diagram of Series Ⅱ suggests that the number of individuals caught within the same basket is less than that in the independent distribution. This might seem to suggest that it is unnecessary, in this case, to give any consideration to the influence of the hooks being occupied, yet it might bring in some errors to think so instantly.

Example C $_{b-y}$ *2* : The direction of the gradient is opposite to each other in both species, and at a glance this seems to represent the influence of the hooks being occupied by individuals of respective species. In this case, however, the gradients were regarded as simple ones and the estimated values in which the influence was

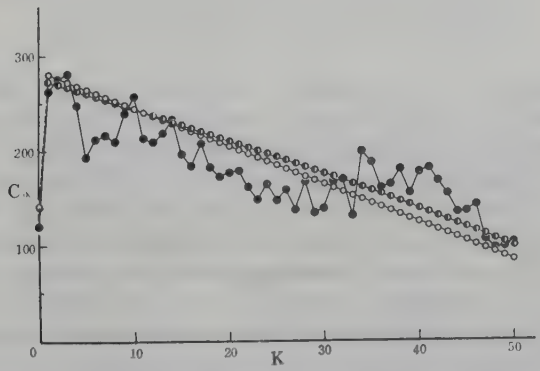


Fig. 13—2 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 2 in the Fishing Ground No. 1).

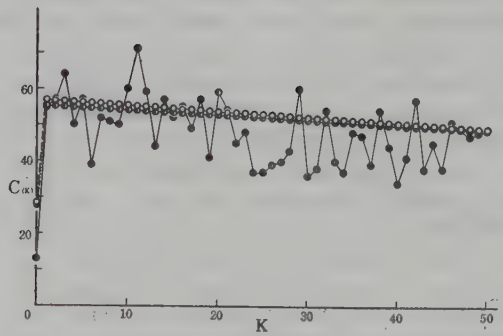


Fig. 13—2 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 2 in the Fishing Ground No. 1).

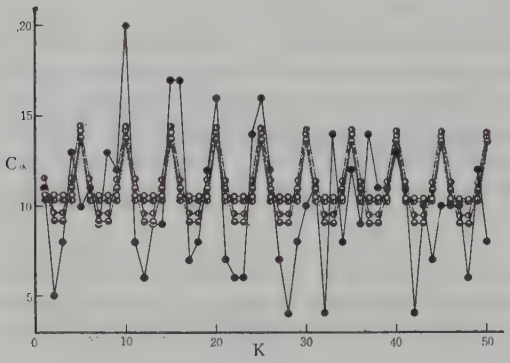


Fig. 13—2 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 2 in the Fishing Ground No. 1).

taken into consideration were computed. However, there still remains a repulsive pattern extending to *ca.* 40 units (40 km) as is seen in the diagram of Series Ⅰ, although this repulsive pattern might be attributable to the existence of a large school of big-eye tuna. But it is impossible to ascertain if this is really assigned to a large school of big-eye tuna. The diagram of Series Ⅱ does not show nothing else than the deviation within a small range. But the diagram of the Series Ⅲ illustrates that a relatively large deviation is observable within the shortest range, *i.e.*, a considerable number of individuals of yellow-fin tuna are caught at the hooks spaced by 8, 10, 15, 16, 24, 33 and 37 hook-intervals from respective hooks occupied by individuals of big-eye tuna, while the number of hooks occupied by yellow-fin tuna and spaced by shorter than 5, 11, 12, 17, 18, 21, 22, 23, the width from 27 to 32 and that from 39 to 50 hook-intervals is far less than those in the case in which individuals of respective

species are distributed independently of each other.

Example C b–y 3 : As the direction of the gradient is the same in both species, the series of the estimated values within the range of k from 0 to not so large a value in which the influence of the gradient of the catch rate is taken into consideration, show values slightly higher than that in the series in which the influence of the gradient is put out of consideration. And it is unnecessary to pay any attention to the influence of the existence of large schools. The diagram of Series I suggests that the individuals of yellow-fin tuna caught at the hooks next to or in the units spaced by 3, 10, 19 and 22 units from respective units occupied by big-eye tuna are a little more abundant than those in the case in which both species are distributed independently of each other. While the individuals of yellow-fin tuna caught within the same units or

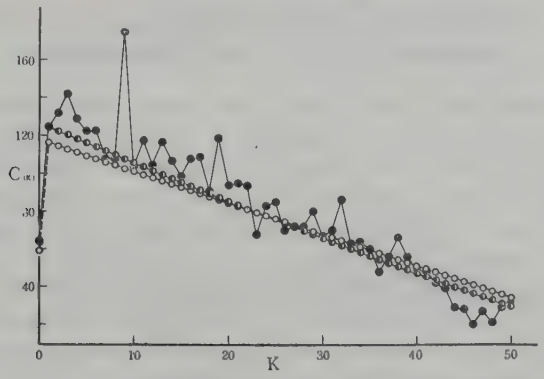


Fig. 13—3 (I). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series I obtained at Station 3 in the Fishing Ground No. 1).

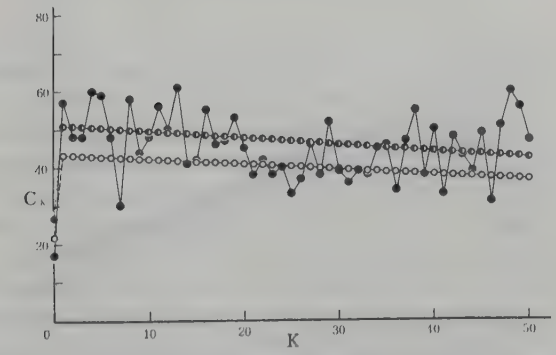


Fig. 13—3 (II). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series II obtained at Station 3 in the Fishing Ground No. 1).

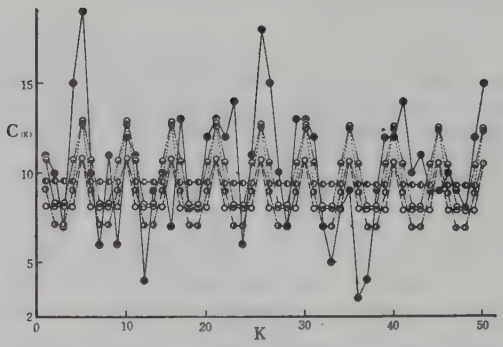


Fig. 13—3 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 3 in the Fishing Ground No. 1).

in the units spaced by 4~8 or longer than 25 units from respective units occupied by big-eye tuna are little less than those in the case in which both species are distributed independently of each other. The observed number of the couples of individuals being constituted of each of yellow-fin tuna and big-eye tuna and spaced by shorter than 20 or longer than 35 baskets is generally larger than the estimated number, while the number of those spaced by 20~35 baskets is a little smaller. The diagram of Series Ⅲ, in which the relation is considered to be shown most in detail, represents that the couples of fishes being constituted of different species and spaced by 4, 5, 22, 25 and 26 hook-intervals are observed more frequently than expected, while those spaced by 12 and 32~37 hook-intervals are less than expected.

Example C b–y 4 : In the relation diagram of Series Ⅰ, the existence of an aggre-

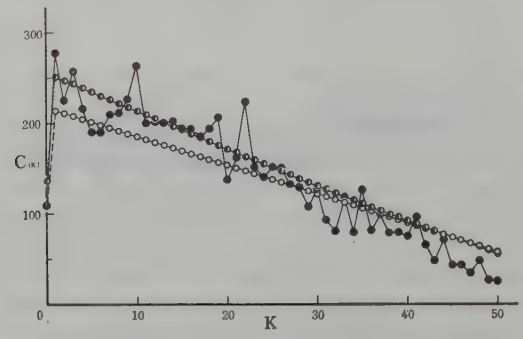


Fig. 13—4 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 4 in the Fishing Ground No. 1).

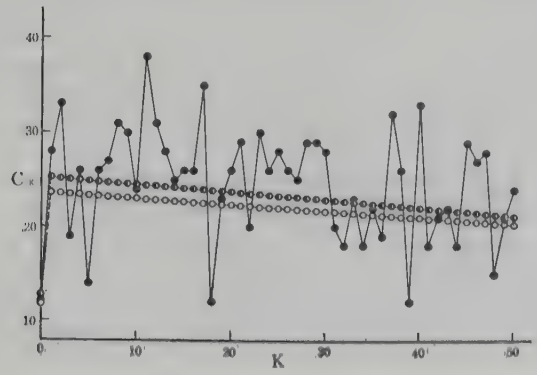


Fig. 13—4 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 4 in the Fishing Ground No. 1).

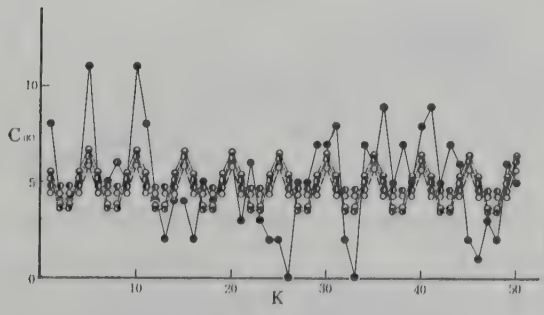


Fig. 13—4 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 4 in the Fishing Ground No. 1).

gative pattern extending to about 40 units (40 km) is suggested, but considering the spatial relation among the individuals of yellow-fin tuna, this pattern is regarded as being considerably affected by the distribution pattern of yellow-fin tuna showing the existence of a school covering about 40 units in the range from the 140th to the 350th basket. Besides this, the observed values are abruptly high in the units at k 9, and this seems to indicate some essential pattern. The observed values in the diagram of Series Ⅱ deviate rather conspicuously from the estimated ones, and this seems to indicate that the unit length adopted in consideration is most adequate. Individuals of yellow-fin tuna caught in the baskets spaced by 2, 8, *ca.* 11, 17, *ca.* 25, 37, 40 and *ca.* 45 baskets from respective baskets occupied by big-eye tuna are more abundant than those in the case when they are distributed independently of each other, while individuals caught in the baskets spaced by 6, 18 and 39 baskets from respective baskets occupied by big-eye tuna are lesser. The diagram of Series Ⅲ suggests that

much more individuals of yellow-fin tuna are caught at the hooks spaced by shorter than 12, *ca.* 30 and 34~44 hook-intervals, especially at the hooks next to or spaced by 5 and 10 hook-intervals from respective hooks occupied by big-eye tuna. However, it is impossible to guess the hook-intervals maintaining low catch rate of yellow-fin tuna, because most of the estimated and observed numbers are fewer than 5.

Example C b-y 5 : The total catch of yellow-fin tuna is extremely low as compared with that of big-eye tuna, and this causes that the relation diagram, especially the variation of the observed values in it, is strongly affected by the distribution of yellow-fin tuna, and moreover, the influence of each individual of yellow-fin tuna upon the distribution pattern and the accidental errors concerning them are apt to be emphasized too much. Accordingly, it is necessary to pay cautious attention to this,

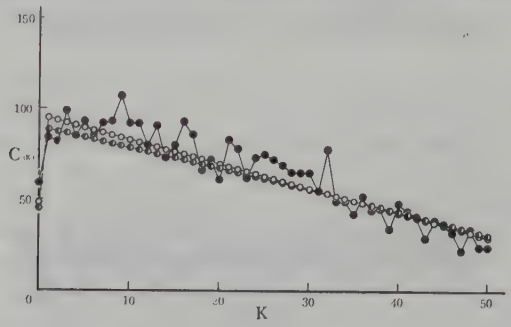


Fig. 13—5 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 5 in the Fishing Ground No. 1).

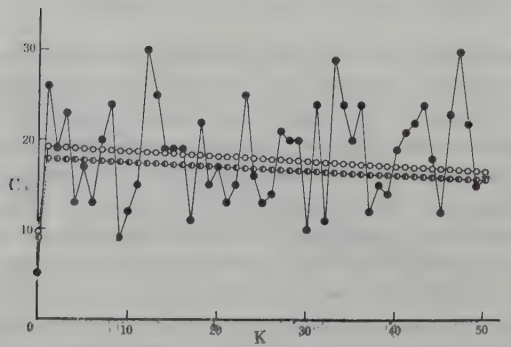


Fig. 13—5 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 5 in the Fishing Ground No. 1).

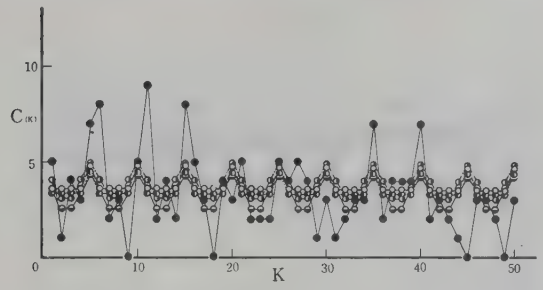


Fig. 13—5 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 5 in the Fishing Ground No. 1).

or rather, exactly speaking, such an example seems to be unsuitable for the analysis, although the observed values may look superficially to be available for the analysis. The diagram of Series Ⅰ seems to suggest that the aggregative pattern covering *ca.* 30 units (30 km) is present, but the existence of such an aggregative pattern seems to be doubtful, when we consider that this might be attributable to the wide school of yellow-fin tuna, the existence of which is, however, somewhat doubtful on account of the scarcity of caught individuals. The same doubt about the relation diagram seems to be increased in the relation diagrams of Series Ⅱ and Ⅲ, consequently no consideration about the distribution pattern is given to them.

Example C b–y 6 : Concerning the Examples C b–y 6 to 10, quite the same error as that mentioned in the preceding example is expected. Thus, the aggregative pattern covering *ca.* 30 units (30 km) in the diagram of Series Ⅰ seems also to be assigned to the distribution pattern of yellow-fin tuna, and consequently it is regarded as insignificant. The number of individuals of yellow-fin tuna caught within the 4 units (4 km)

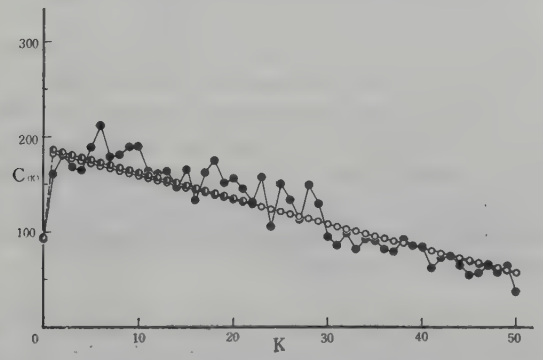


Fig. 13—6 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 6 in the Fishing Ground No. 1).

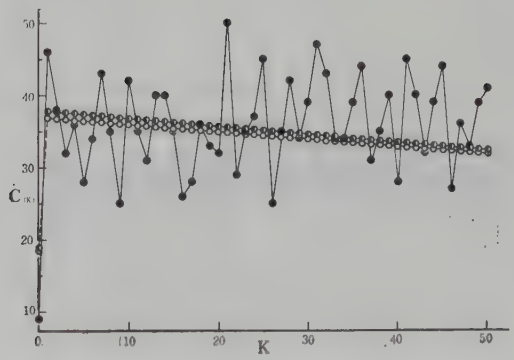


Fig. 13—6 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 6 in the Fishing Ground No. 1).

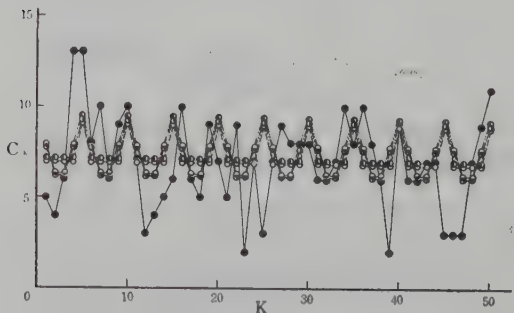


Fig. 13—6 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 6 in the Fishing Ground No. 1).

from respective units occupied by big-eye tuna is less than that in the case when individuals of both species are distributed independently of each other. The diagram of Series Ⅱ indicates that the distance between the individuals of yellow-fin tuna and big-eye tuna shows the periodicity of the length shorter than 3 baskets (600 m). The observed values in the diagram of Series Ⅲ show an apparent deviation of the small amplitude but of the rather long periodicity, but this is evidently caused by the scarcity of the caught individuals of yellow-fin tuna, consequently this distribution and the periodicity are regarded as insignificant.

Example C b–y 7 : The relation diagram of Series Ⅰ resembles closely that of the Example Y 7 holding rather few individuals caught. Namely, the spatial correlation between the big-eye tuna and yellow-fin tuna seems to be strongly affected by the distribution pattern of the subordinate species, yellow-fin tuna. Thus it is somewhat

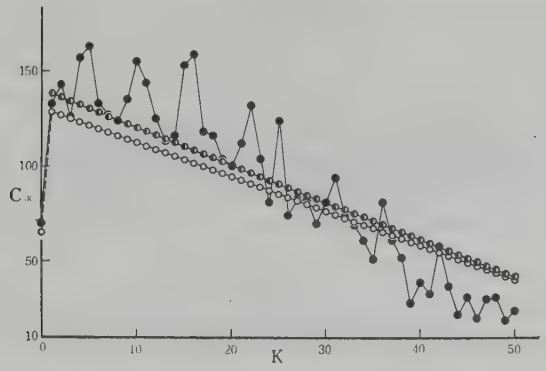


Fig. 13—7 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 7 in the Fishing Ground No. 1).

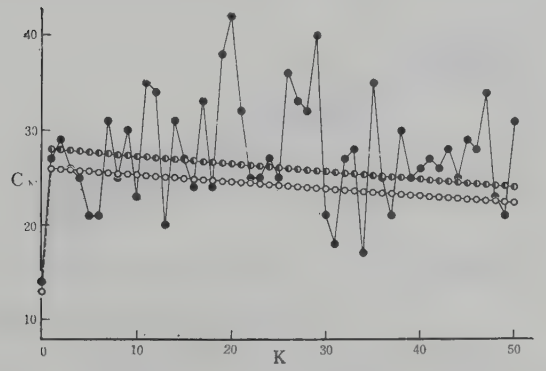


Fig. 13—7 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 7 in the Fishing Ground No. 1).

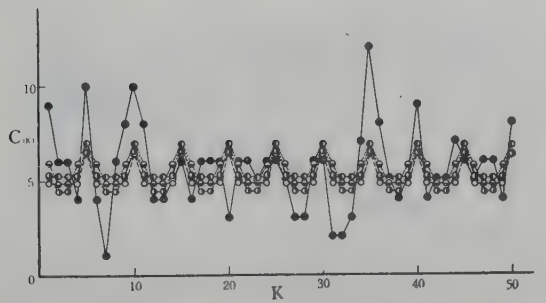


Fig. 13—7 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 7 in the Fishing Ground No. 1).

doubtful whether this diagram is worthy to be analyzed or not. The diagram of Series Ⅱ suggests that the individuals of yellow-fin tuna caught in the baskets spaced by shorter than 6 baskets (1.2 km) from respective baskets occupied by big-eye tuna are lesser. While the individuals of yellow-fin tuna caught in the baskets spaced by about 11, 20 and 28 baskets from respective ones occupied by big-eye tuna are more abundant. The diagram of Series Ⅲ indicates that the individuals of yellow-fin tuna caught at the hooks next to or spaced by 5, 9, 10, 11, 35, 36 and 40 hook-intervals from respective ones occupied by big-eye tuna are a little more abundant than expected.

Example C b–y 8 : It is unnecessary to pay any attention to the analyzing of the diagram of Series Ⅰ, because both yellow-fin tuna and big-eye tuna do not form any

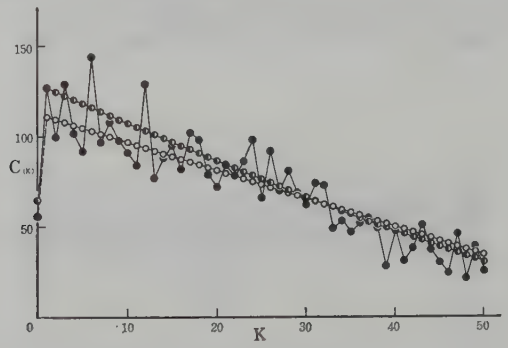


Fig. 13—8 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 8 in the Fishing Ground No. 1).

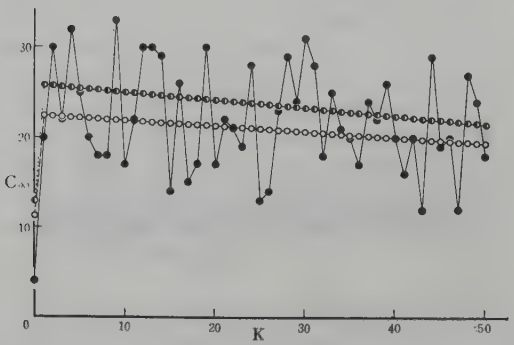


Fig. 13—8 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 8 in the Fishing Ground No. 1).

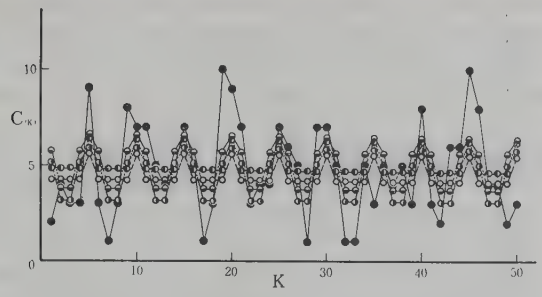


Fig. 13—8 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 8 in the Fishing Ground No. 1).

large schools in this example. The deviation of the observed values from the estimated ones alludes to the existence of a rather repulsive distribution extending to *ca.* 20 units (20 km) or a little longer between the individuals of both species, although some fairly conspicuous relation pattern within a shorter range is also suggested by this. The diagram of Series Ⅱ suggests roughly that the individuals of yellow-fin tuna caught in the baskets next to or spaced by 1, *ca.* 7, the width from 15 to 25 baskets *etc.* from respective ones occupied by big-eye tuna are slightly lesser. Both the estimated and observed values are low and some accidental errors are expected, but it seems to be said safely that more individuals of yellow-fin tuna than expected are caught at the hooks spaced by *ca.* 4 hook-intervals or 9 baskets from respective hooks occupied by big-eye tuna and contrarily lesser individuals of yellow-fin tuna are caught at the hooks spaced by shorter than 1½ baskets, 17, 28, 32 and 33 hook-intervals from respective hooks occupied by big-eye tuna.

Example C b–y 9 : Despite of the fact that the total catch of yellow-fin tuna is

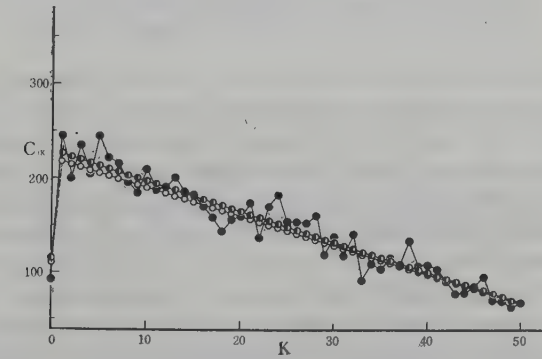


Fig. 13—9 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 9 in the Fishing Ground No. 1).

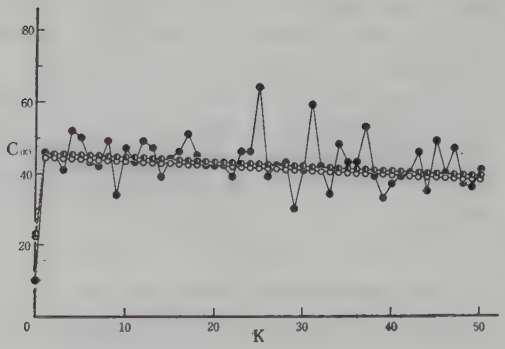


Fig. 13—9 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 9 in the Fishing Ground No. 1).

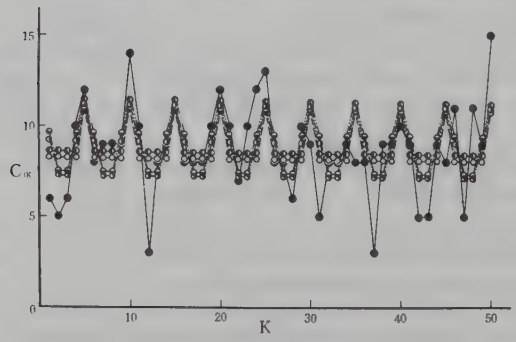


Fig. 13—9 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 9 in the Fishing Ground No. 1).

not so large and its observed values deviate much from the estimated ones, the influence of the distribution pattern of the subordinate species, yellow-fin tuna, is nearly invisible and quite a different relation diagram is obtained, which indicates that individuals of yellow-fin tuna and big-eye tuna are distributed almost independently of each other. The diagram of Series Ⅱ supports the above-mentioned fact and further shows that the number of individuals of yellow-fin tuna caught in the same baskets occupied by big-eye tuna is only a half of the expected number, but the number of individuals of yellow-fin tuna caught in the following 24 baskets next to respective ones occupied by big-eye tuna is almost as large as those in the case when individuals of both species are distributed independently of each other. While the number of individuals of yellow-fin tuna caught in the 25 successive baskets spaced by 24 baskets from respective ones occupied by big-eye tuna deviates much from the expected ones. The

diagram of Series Ⅲ gives the more detailed structure that the number of individuals of yellow-fin tuna caught at the hooks spaced by shorter than 1 basket, 12, 31, 37, 42, 43 and 45 hook-intervals from respective hooks occupied by big-eye tuna is less than expected, while that at the hooks spaced by 10, 23～25 and 50 hook-intervals is larger.

Example C b–y 10 : It seems unnecessary to pay any attention to the analyzing of the diagram of Series Ⅰ of this example for the same reason as mentioned about the Example C *b–y* 9. A rather strong repulsive pattern extending to 3–unit width (3 km) is observable, besides the existence of a rather long periodic but weak deviation of the observed values and that the individuals of yellow-fin tuna caught in the units spaced by 13～18 unit-width from respective ones occupied by big-eye tuna are more abundant. The observed values in the diagram of Series Ⅲ, supporting the existence of the strongly repulsive pattern detected in the diagram of Series Ⅰ, show a deviation narrow but with large amplitude. As the observed and estimated values are scarce, it seems unreasonable to give any further consideration to the diagram of Series Ⅱ.

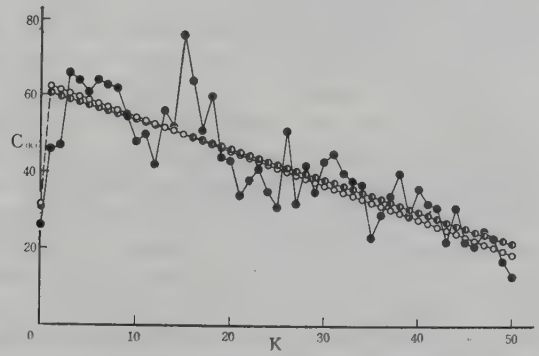


Fig. 13—10(Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 10 in the Fishing Ground No. 1).

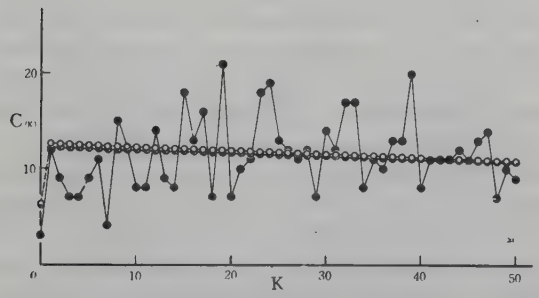


Fig. 13—10(Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 10 in the Fishing Ground No. 1).

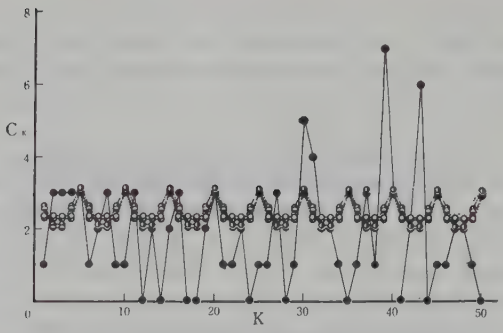


Fig. 13—10(Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 10 in the Fishing Ground No. 1).

2) Correlation between tunas and marlins

It seems to be very important and at the same time necessary for the ecological and commercial purposes to examine the spatial relation between the individuals of tunas and marlins or tunas and sharks. But the number of individuals of tunas of all the examples examined here is apart too far from that of marlins or sharks and this may result in the fact that the relation diagram is strongly affected by the distribution pattern of the subordinate species, as mentioned already in the preceding section. Unfortunately, there is no example, in which the catch rate of marlins or sharks is considerably high and nearly at the same level as that of tunas. Accordingly, all the examples are unsuitable for the present examination. Nevertheless, several examples, in which the catch rate of tunas is extremely low and nearly at the same level as that of marlins or sharks, are taken up for the purpose to remove the above-mentioned error and at the same time to show some examples obtained from the old fishing grounds of lower productivity, because most of the above-mentioned examples are all obtained from rather new fishing grounds.

The catch rate is very low in both tunas and marlins, consequently the observed values in Series Ⅲ, even in Series Ⅱ sometimes, become extremely low; thus the correlation diagram of Series Ⅲ is omitted from this paper and the consideration is made chiefly on that of Series Ⅰ. Besides the correlation diagrams, the relation diagrams of respective single speices are illustrated to aid the analyses, although no discussion is given here on them.

Although the correlation diagrams seem to show, as expected, some repulsive pattern, it is impossible to judge definitely whether this is an essential one or not and to know what the difference is between this relation and that between big-eye tuna and yellow-fin tuna, because the catch rate is too low. Yet, it is noticeable that the correlation diagram of Series Ⅰ of the Example C t–m 2 is one of the typical examples, in which the correction term for the influence of the gradients of the catch rates, the directions of which are opposite to each other, is extremely large.

Exposition of particular example

Example C t–m 1 : A rather typical repulsive pattern is observable in the diagrams

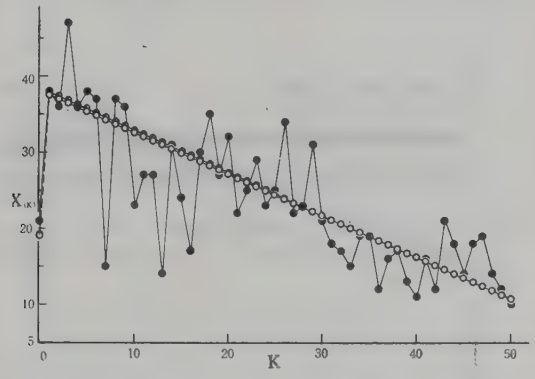


Fig. 14—1 (Ⅰ). X(k)—k relation diagram of tunas
(Series Ⅰ obtained at Station 1 in the Fishing Ground No.3).

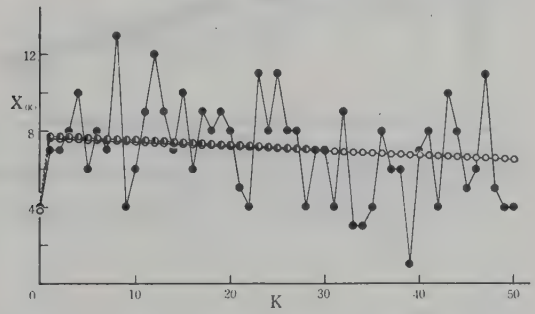


Fig. 14—1 (Ⅱ). X(k)—k relation diagram of tunas
(Series Ⅱ obtained at Station 1 in the Fishing Ground No.3).

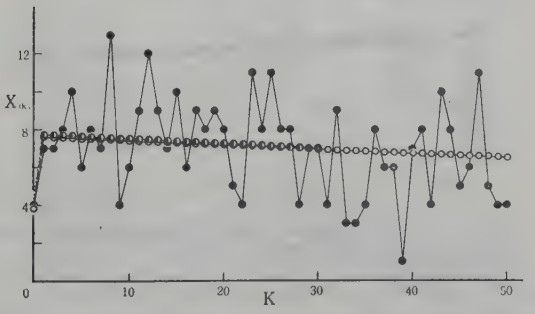


Fig. 15—1 (Ⅰ). X(k)—k relation diagram of marlins
(Series Ⅰ obtained at Station 1 in the Fishing Ground No.3).

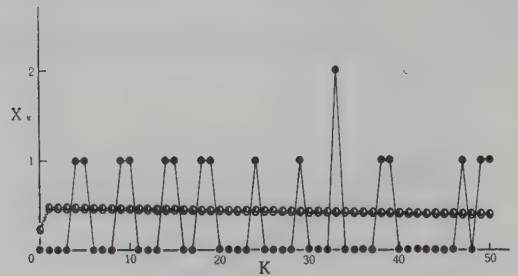


Fig. 15—1 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 1 in the Fishing Ground No. 3).

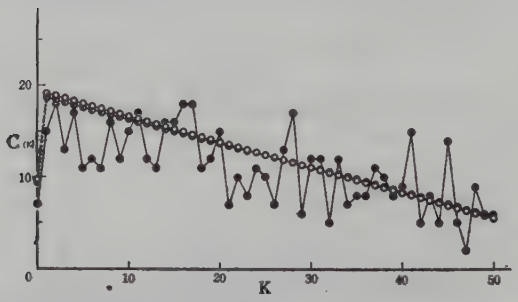


Fig. 16—1 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 1 in the Fishing Ground No. 3).

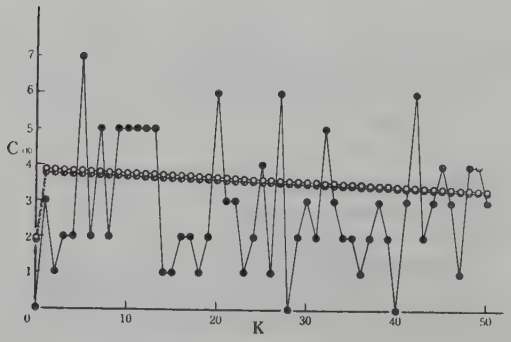


Fig. 16—1 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 1 in the Fishing Ground No. 3).

of Series Ⅰ and Ⅱ, although the short periodic deviations are observed and some accidental errors are expected.

Example C t–m 2 : As the gradient of the catch rate of marlins towards the opposite direction to the increase of the soaking time is conspicuous, the correction term of the theoretical values for the influence of the gradient becomes large, al-

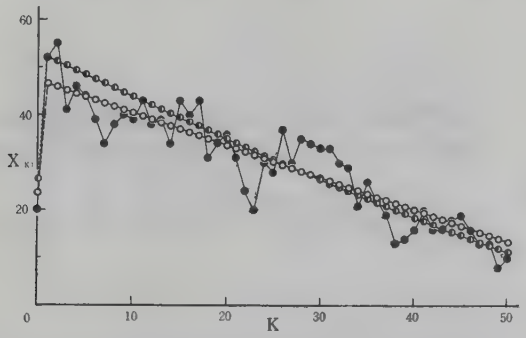


Fig. 14—2 (Ⅰ). X(k)—k relation diagram of tunas
(Series Ⅰ obtained at Station 2 in the Fishing Ground No. 3).

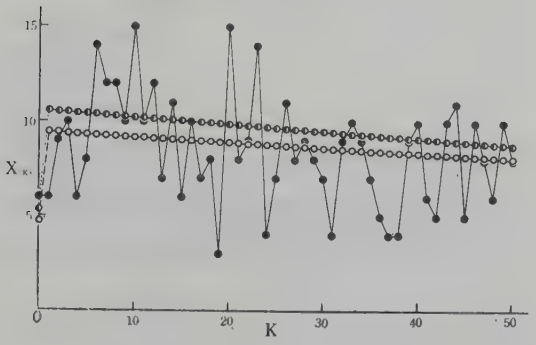


Fig. 14—2 (Ⅱ). X(k)—k relation diagram of tunas
(Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

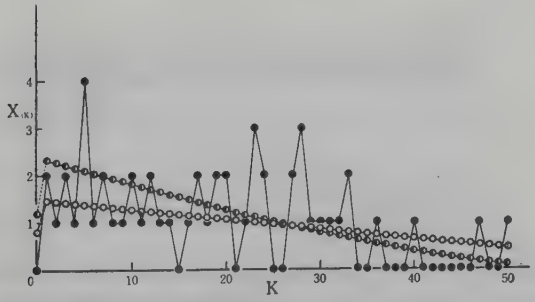


Fig. 15—2 (Ⅰ). X(k)—k relation diagram of marlins
(Series Ⅰ obtained at Station 2 in the Fishing Ground No. 3).

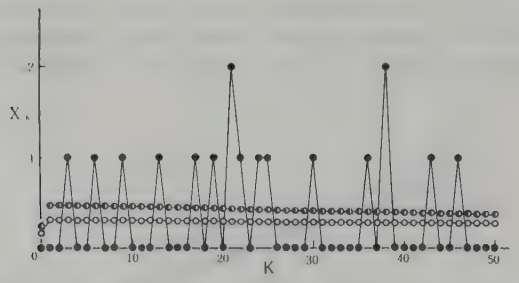


Fig. 15—2 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

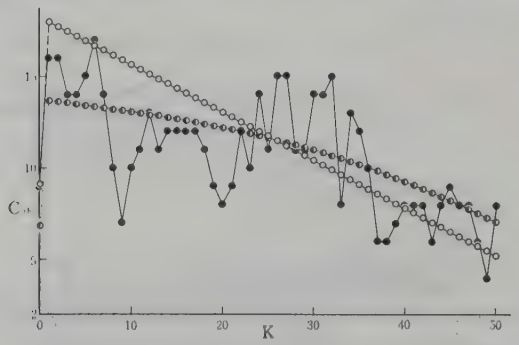


Fig. 16—2 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 2 in the Fishing Ground No. 3).

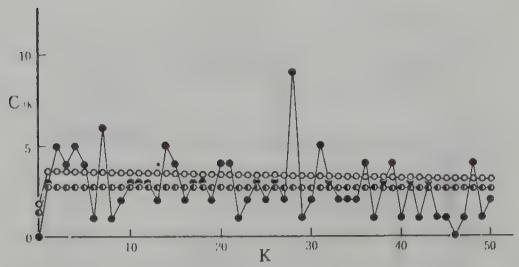


Fig. 16—2 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

though the gradient of marlins itself seems to contain some accidental errors, because the catch rate of marlins is so low. Accordingly the significance of the correction term might also be somewhat doubtful. For this reason, together with lower observed

and estimated values, no discussion can be made upon the diagrams of this example.

Example C t–m 4 : As both the catch rate and observed values are low in both

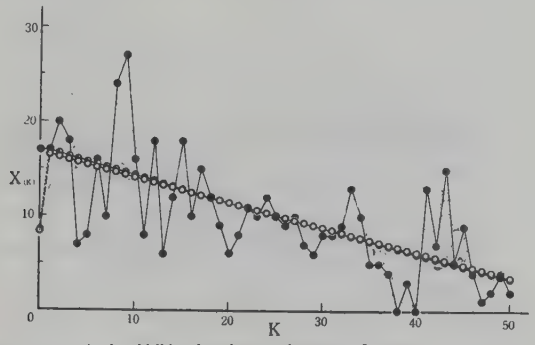


Fig. 14—4 (Ⅰ). X(k)—k relation diagram of tunas
(Series Ⅰ obtained at Station 4 in the Fishing Ground No.3).

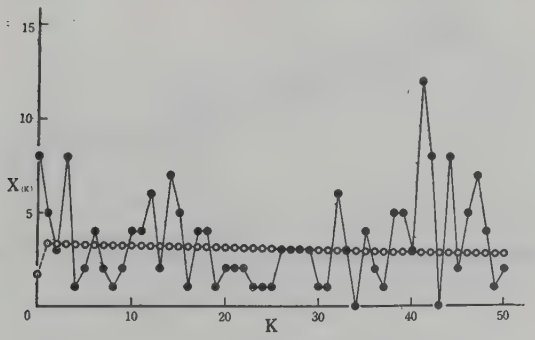


Fig. 14—4 (Ⅱ). X(k)—k relation diagram of tunas
(Series Ⅱ obtained at Station 4 in the Fishing Ground No.3).

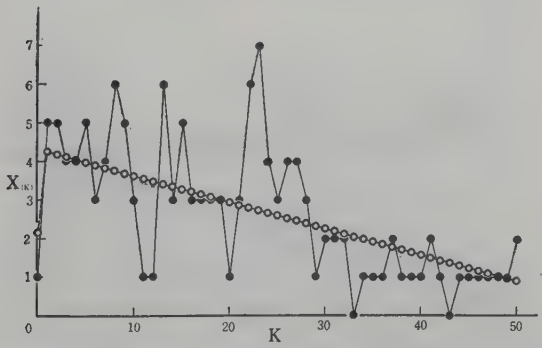


Fig. 15—4 (Ⅰ). X(k)—k relation diagram of marlins
(Series Ⅰ obtained at Station 4 in the Fishing Ground No.3).

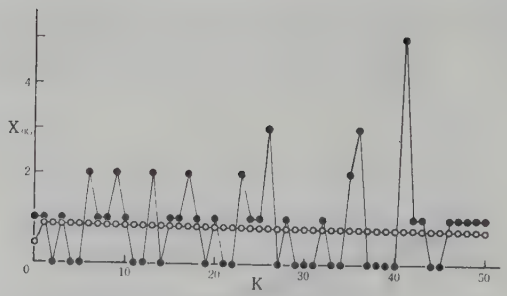


Fig. 15—4 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

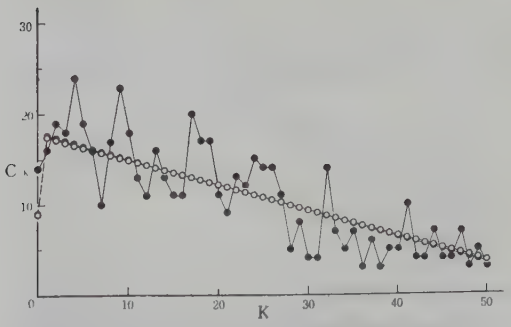


Fig. 16—4 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 4 in the Fishing Ground No. 3).

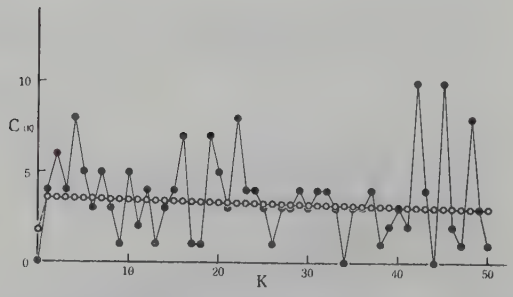


Fig. 16—4 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

species, the significance of the short periodic deviation of the observed values in the diagrams is highly doubtful and further consideration is set aside.

Example C t–m 5 : The long periodic deviation of the observed values in the diagram of Series Ⅰ seems to allude to something like a distribution pattern, but the lower observed values make it impossible to progress the analyses further.

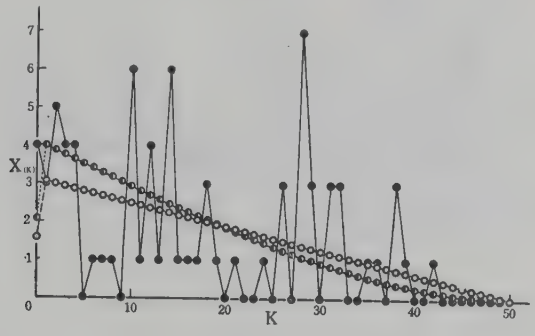


Fig. 14—5 (Ⅰ). X(k)—k relation diagram of tunas
(Series Ⅰ obtained at Station 5 in the Fishing Ground No.3).

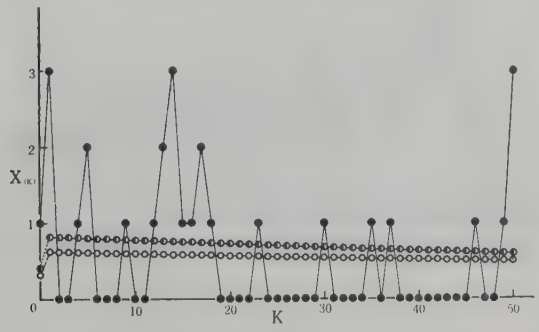


Fig. 14—5 (Ⅱ). X(k)—k relation diagram of tunas
(Series Ⅱ obtained at Station 5 in the Fishing Ground No.3).

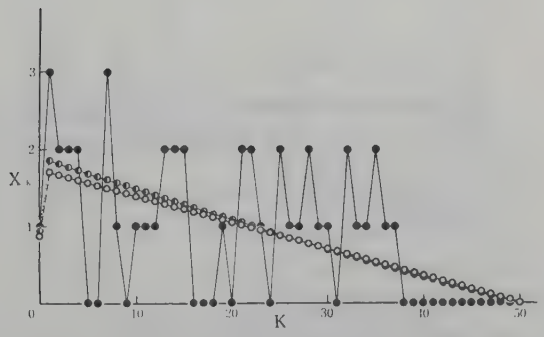


Fig. 15—5 (Ⅰ). X(k)—k relation diagram of marlins
(Series Ⅰ obtained at Station 5 in the Fishing Ground No.3).

Fig. 15—5 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 5 in the Fishing Ground No. 3).

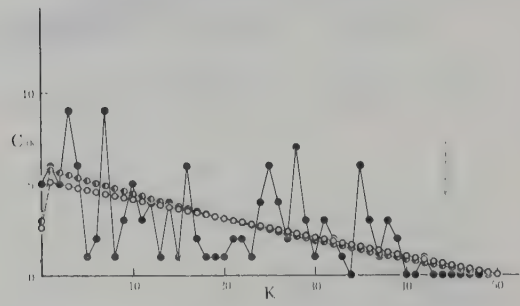


Fig. 16—5 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 5 in the Fishing Ground No. 3).

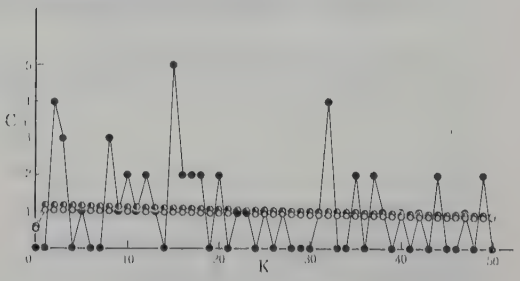


Fig. 16—5 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 5 in the Fishing Ground No. 3).

3) Correlation between tunas and sharks

The marlin is situated at a little higher food rank than tuna, but there is no direct predatory relation between them. While it is a well known fact that the hooked

tuna is frequently damaged by sharks, although it is uncertain whether freely swimming tunas are attacked by sharks as well as hooked ones or not. Anyhow, there are cases in which many sharks are hooked around the parts where abundant tunas are hooked and contrarily the cases in which tunas are hooked avoiding the parts where abundant sharks are hooked. Indeed this is a very serious problem from the commercial point of view, because damaged tunas have no market value. Some adequate examples for the preceding analyses of the correlation between tunas and marlins may be obtainable, as the latter has the commercial value as high as or higher than the former, while it seems hardly possible to get any suitable examples for the analyses of the correlation between tunas and sharks, because it is quite unreasonable to set gears in the waters where a plenty of sharks, which have no commercial values and moreover damage tunas having high commercial value, are swarming, although we wish earnestly to clear out this relation.

Very unfortunatly, no example, sufficient and suitable for the analyses of this important but complicated relation, was obtained; only several instances are illustrated below as examples.

Exposition of particular example

Example C t-s 1 : The correlation diagram of Series I seems superficially to allude to some pattern, but when this is compared carefully with the relation diagram of sharks, it becomes clear that this correlation diagram is obtainable by simply amplifying the observed values in the relation diagram of sharks. And actually nothing else can be deduced from this diagram than that tunas and sharks are distributed almost independently of each other. No consideration was given to the diagram of Series II.

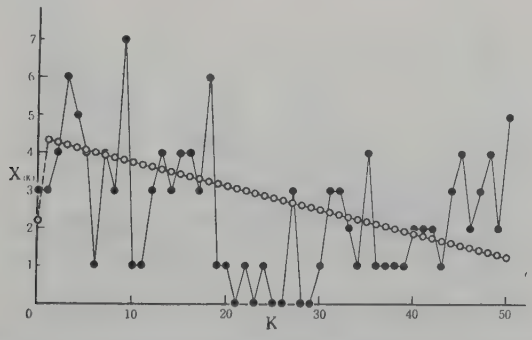


Fig. 17—1 (I). X(k)—k relation diagram of sharks
(Series I obtained at Station 1 in the Fishing Ground No. 3).

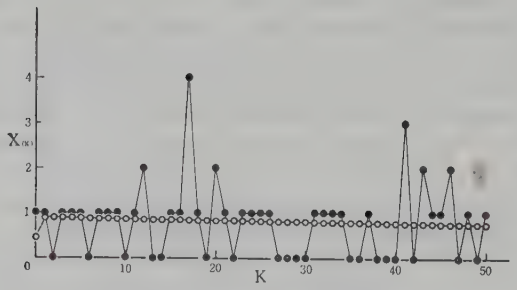


Fig. 17—1 (Ⅱ). X(k)—k relation diagram of sharks
(Series Ⅱ obtained at Station 1 in the Fishing Ground No. 3).

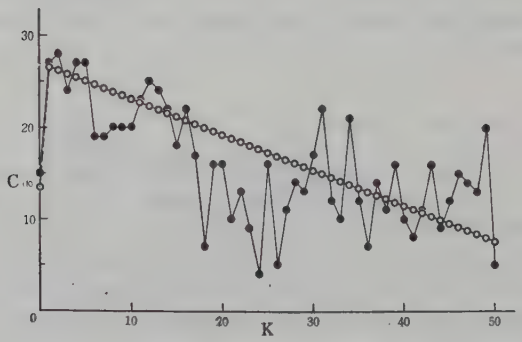


Fig. 18—1 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅰ obtained at Station 1 in the Fishing Ground No. 3).

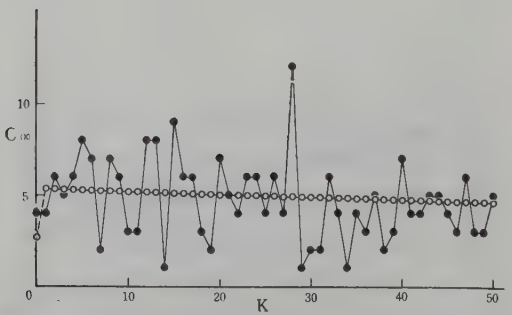


Fig. 18—1 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅱ obtained at Station 1 in the Fishing Ground No. 3).

Example C t-s 2 : Although some accidental errors are expected on account of the scarcity of caught sharks, it seems likely that the individuals of tuna caught in the

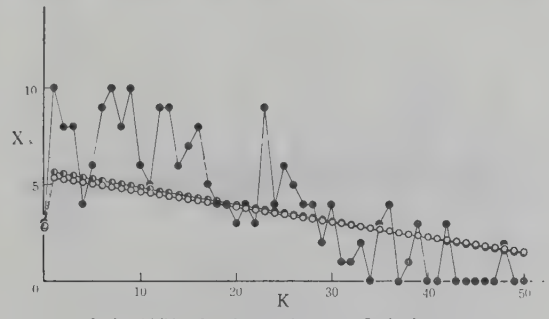


Fig. 17—2 (Ⅰ). X(k)—k relation diagram of sharks
(Series Ⅰ obtained at Station 2 in the Fishing Ground No. 3).

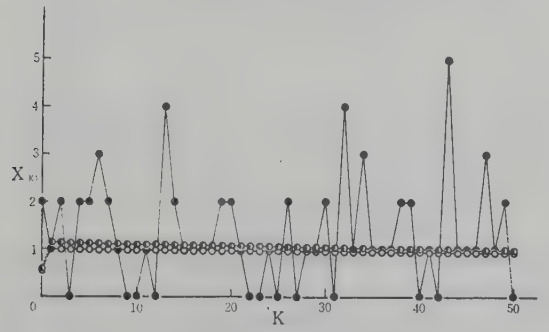


Fig. 17—2 (Ⅱ). X(k)—k relation diagram of sharks
(Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

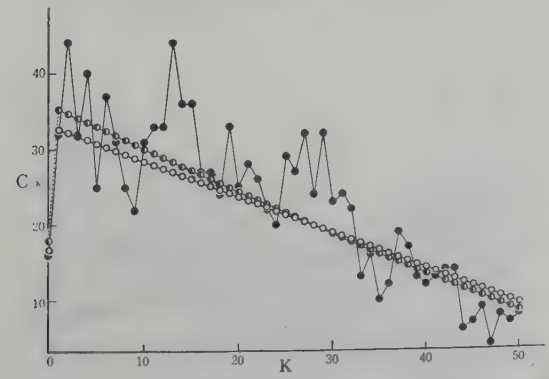


Fig. 18—2 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅰ obtained at Station 2 in the Fishing Ground No. 3).

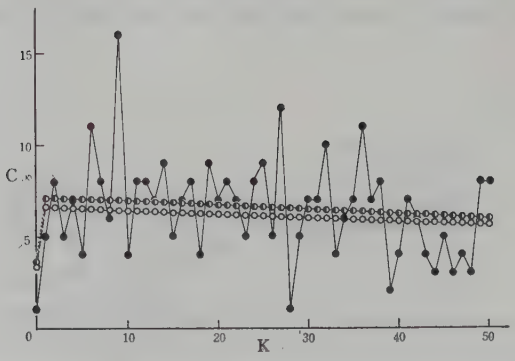


Fig. 18—2 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks (Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

units spaced by about 13 or about 28 units (13 or 28 km) from the respective units occupied by sharks are a little more abundant and that sharks are distributed rather aggregatively in the ranges a little shorter than 20 units (20 km). No description is given for the diagram of Series Ⅱ.

Example C t–s 4 : As in the preceding example, it is very difficult to deduce any results from the correlation diagram of Series Ⅰ, because this seems to reflect too strongly the distribution pattern of sharks, which, however, may indicate some structures.

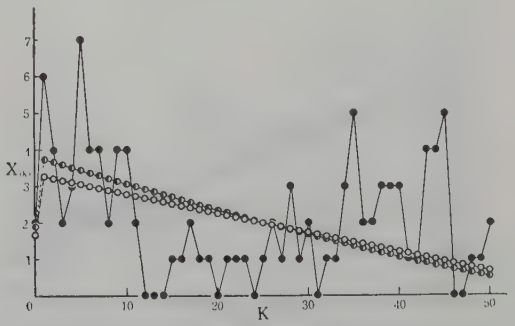


Fig. 17—4 (Ⅰ). X(k)—k relation diagram of sharks (Series Ⅰ obtained at Station 4 in the Fishing Ground No. 3).

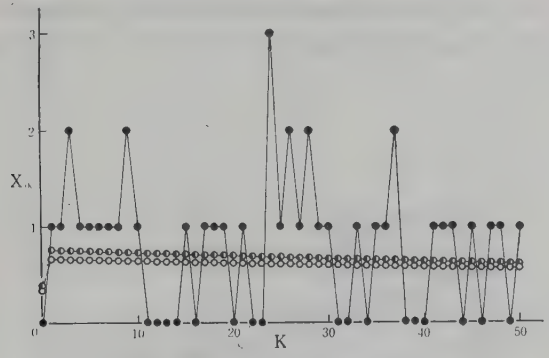


Fig. 17—4 (Ⅱ). X(k)—k relation diagram of sharks
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

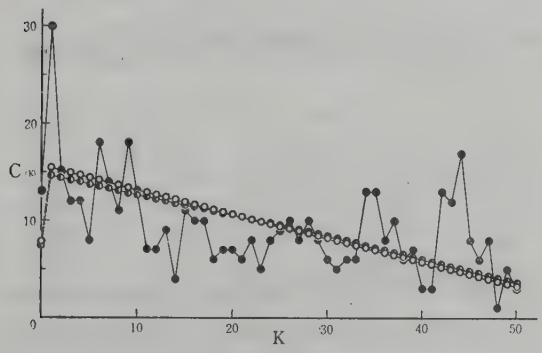


Fig. 18—4 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅰ obtained at Station 4 in the Fishing Ground No. 3).

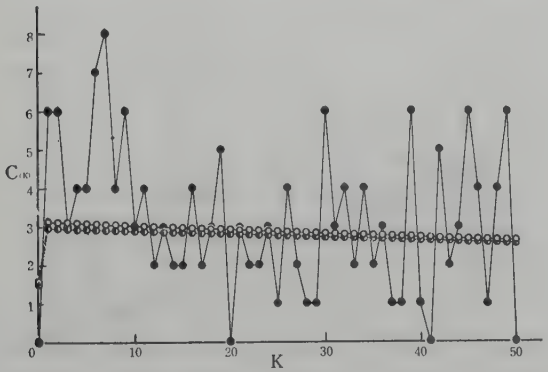


Fig. 18—4 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

Example C t–s 5 : The lower observed values chiefly attributable to the low catch rate of sharks make it impossible to give any consideration to this example.

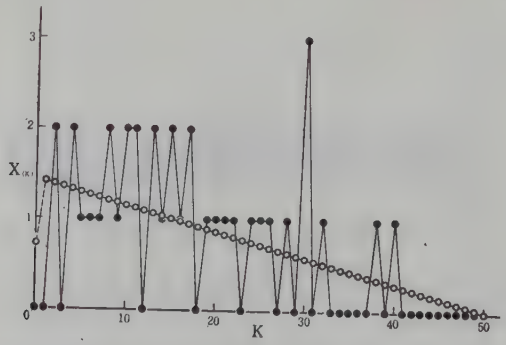


Fig. 17—5 (Ⅰ). X(k)—k relation diagram of sharks
(Series Ⅰ obtained at Station 5 in the Fishing Ground No. 3).

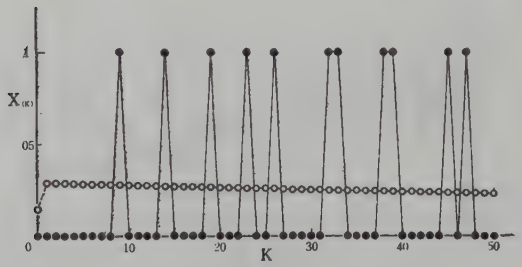


Fig. 17—5 (Ⅱ). X(k)—k relation diagram of sharks
(Series Ⅱ obtained at Station 5 in the Fishing Ground No. 3).

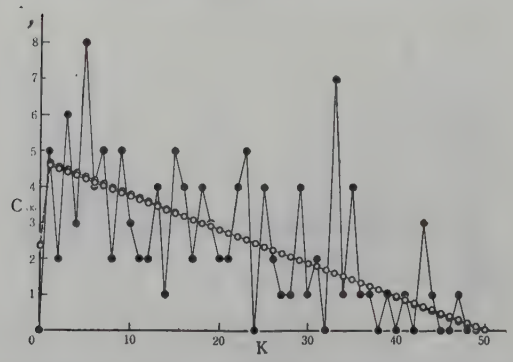


Fig. 18—5 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅰ obtained at Station 5 in the Fishing Ground No. 3).

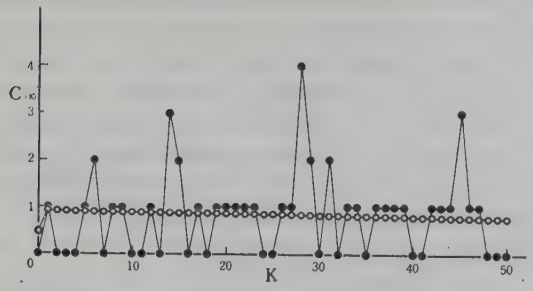


Fig. 18--5 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅱ obtained at Station 5 in the Fishing Ground No.3).

Discussion

1. Errors assigned to the fishing method

As mentioned already in the chapter of "method and material", the gears are set in about 3 hours and hauled up usually after 3 hours drifting, and it takes about 12 hours for a whole hauling. Accordingly, besides the influence of the gradient of the soaking time, which is corrected in the construction of formulae, the influence of the duration of the soaking time at respective parts of the gear must be taken into consideration. This means that the apparent distribution pattern along the long-line is considered to reflect exactly a section of the distribution of tuna in the ocean only when the swimming sphere of tuna during the soaking time is regarded to be negligibly small as compared with the scale of the distribution pattern under consideration. But such large pelagic fishes as tuna are commonly recognized as active swimmers, consequently it is necessary to give special consideration to the fact that there is no evidence supporting that individuals regarded to form apparent groups, especially the groups larger than those expressed in previous sections as aggregations, were caught within a limited period, because the distribution of tuna at respective parts along the row of gears represents the integrated pattern during the time from the setting to hauling of respective parts——3 hours in the shortest case and *ca.* 21 hours to up to a whole day in the longest one. It might be effective to find out some clue to clear up this problem, that some characteristics, such as the living or dead state, body length, stomach contents and the degree of the contamination by fission products, are compared with one another among the individuals caught at the neighbouring hooks. But actually, for the reasons mentioned below, the correlation coefficients between the distance among the localities of hooked fishes and these characteristics are too low, as already reported (Maéda, 1955) to be available to clear up the problem. The estimated values represent the expected values in the case when all indi-

viduals are distributed by chance, and the school formation affects only on the value (observed values — estimated ones). But (observed values — estimated ones) by estimated values is very small in most examples and this seems to support that the contagious or self-spacing degree is not so prominent. Moreover, if it is possible to distinguish the catch at successive hooks attributable to schooling from that caused by the chance distribution, there is still no distinct evidence supporting that various characteristics must resemble one another more closely among the individuals belonging to the same group than among the individuals belonging to different groups. However, it seems not to be so significant to give any definite solution for this problem, because the outline of the distribution pattern can be regarded as nearly by chance, although the distortion of the observed values from the estimated ones might be assessed too largely, as too much concerns were paid to emphasize the distortion of the distribution pattern from the chance distribution in every example of the particular exposition.

On the other hand, the analyzing method adopted in this paper is based on the assumption that only the individuals of a single species are fished by the long-line and the probability of respective hooks being occupied by fishes is quite constant. But actually, a small number of hooks are occupied by sharks, other species of tuna and other fishes, some of baits may be stolen or lost without fishes being hooked. Some fishes might come near the hooks but not attracted by baits, some might only take baits but not be caught by hooks, and some others might be caught once but soon escaped from the hook before they were hauled. Moreover there are probably some individuals which come across the long-line but pass through between the hooks without encountering with any hooks with bait. These factors for errors deform the distribution of fishes into a discontagious pattern and produce lower $X(k)$ than that which can be seen under the ideal conditions. In order to estimate the influences of the above-mentioned factors, the correction must be made at every hook which is not availed for the above-mentioned reasons; and this is a very difficult and troublesome work, though not impossible, because the exact catch rate of respective hooks differs according to their situation in each basket, the order of each basket or both of them. Therefore, it is inevitable that the estimated values are not quite free from any of slight errors. I believe, however, that the trends deduced from the preceding analyses do not differ so much from the actual ones, because the above-mentioned unavailable hooks seem not to be so abundant as compared with the total number of hooks, although no adequate method has been found to check exactly the number of individuals passing through the long-line without being caught by the hooks and then to estimate its proportion to all individuals which might come across the gears.

In addition to the above-mentioned factors for errors, which are all effective to diminish the contagiousness of the observed values, another factor seeming somewhat specific to the long-line, must be taken into consideration. Namely, the occupation of hooks by the individuals makes those hooks unavailable for other individuals of the same species, thus the probability of individuals being caught is much decreased by the

sections in which hooks are mostly occupied, this is especially pronounced in heavily occupied parts and in the course of analysis of Series Ⅱ, because the number of hooks in respective sections is confined to 4, consequently the catch rate of respective sections is obliged to be unified more prominently than actually is, consequently the distribution pattern may be misregarded as less contagious. The tendency to keep a slightly self-spacing pattern as being suggested in Example A 12, A 30, A 33, A 34, A 36, and A 41, which are all considered to contain large schools, can be regarded as reflecting the above-mentioned process, although no decisive method is not yet known to distinguish the self-spacing patterns attributable to the above-mentioned process from those of the essential character.

Besides the above-mentioned errors due to the fishing method itself, there is another error effective on the observed values in Series Ⅰ and caused by the difference of the way to take the series of catches within 5 consecutive baskets, because there are 5 ways to section a row of gears by 5 consecutive baskets differing according to the situation of the starting point to count the units, and slight differences are expected in the size of catches between these five ways. In order to confirm the degree of this error, several examples, randomly chosen, are sectioned by 5 consecutive baskets starting at various baskets, and the series of the observed values are illustrated in Fig. 19, which indicates that when the total catch is not so small, the general tendency of deviation does not differ so much, although the phase lag of 1 pitch or the appearance or disappearance of discontinuously high or low values may frequently be observed. Accordingly, the magnitude of the deviation considered together, the errors caused by the above-mentioned fact should be taken into consideration when the total catch is less than 60, although it is unnecessary to estimate the series of the observed values being started at baskets other than the first.

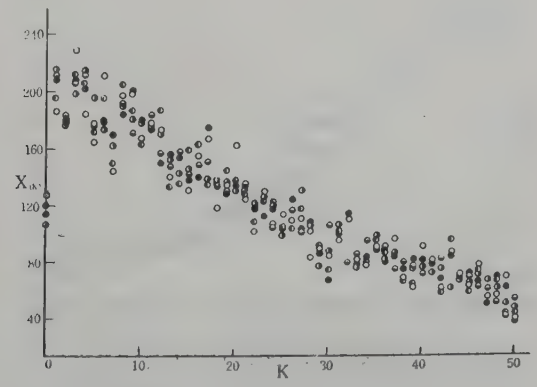


Fig. 19—1. Deviation of the observed values due to from where one starts counting the units (Example B 1').
Note : ● : from the first basket. ○ : from the 2nd basket.
◐ : from the 3rd basket. ◑ : from the 4th basket.
◒ : from the 5th basket.

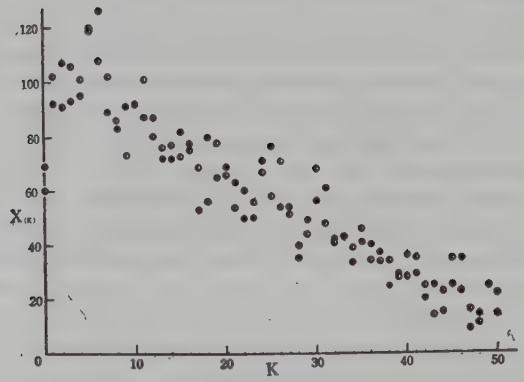


Fig. 19—2. Deviation of the observed values due to from where one starts counting the units (Example B 8).
Note : The same as in Fig. 19—1.

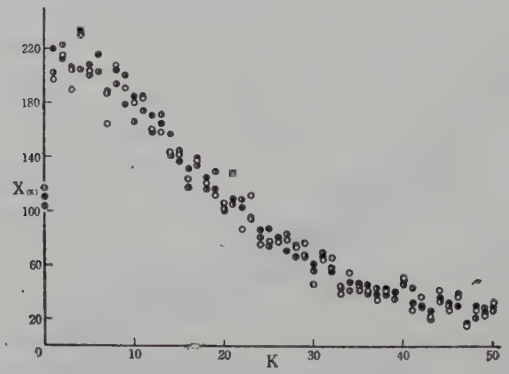


Fig. 19—3. Deviation of the observed values due to from where one starts counting the units (Example B 15).
Note : The same as in Fig. 19—1.

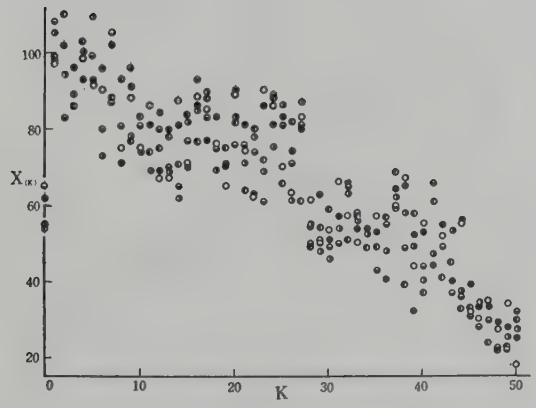


Fig. 19—4. Deviation of the observed values due to from where one starts counting the units (Example Y 1).
Note : The same as in Fig. 19—1.

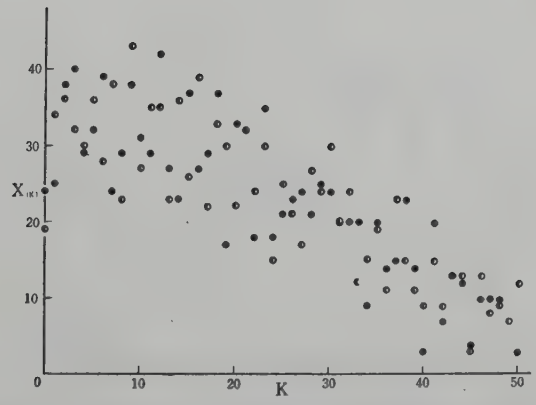


Fig. 19—5. Deviation of the observed values due to from where one starts counting the units (Example Y 8).
Note : The same as in Fig. 19—1.

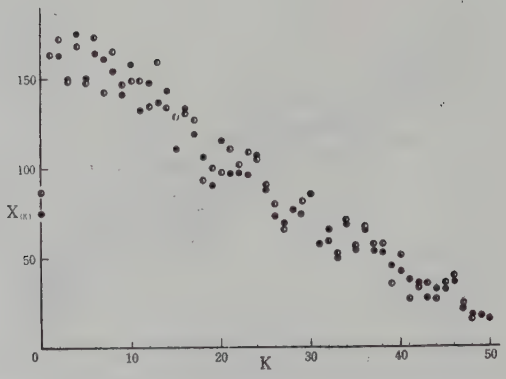


Fig. 19—6. Deviation of the observed values due to from where one starts counting the units (Example A 9).
Note : The same as in Fig. 19—1.

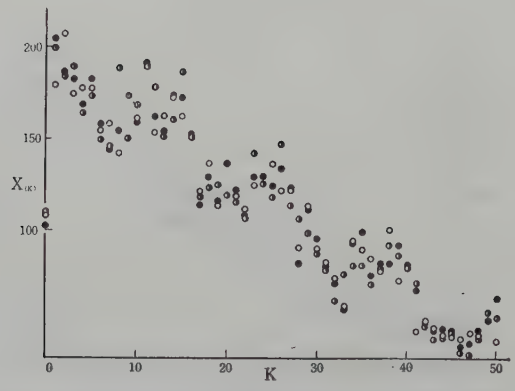


Fig. 19—7. Deviation of the observed values due to from where one starts counting the units (Example A 27).
Note : The same as in Fig. 19—1.

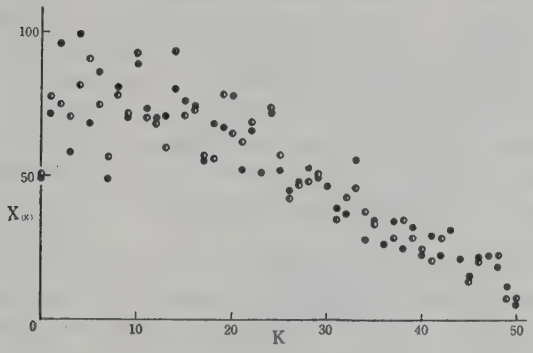


Fig. 19—8. Deviation of the observed values due to from where one starts counting the units (Example A 35).
Note : The same as in Fig. 19—1.

2. Errors contained in the estimated values and the necessity of correcting the influence of the gradient

Besides the errors contained in the observed values, the theoretically estimated values also contain some errors attributable to the uncertainty of constants computed from the actually observed distribution. In constructing the formulae, the gradient of the catch rate was regarded as being simply assigned to the gradient of the soaking time. But the existence of schools of various sizes was ascertained as shown in the results of analyses. Therefore, if some heavily crowded schools are caught at the parts other than the middle of a row, the coefficient of gradient, ΔP, may be frequently over-estimated or rarely under-estimated, because the examples containing schools with their centers in the latter half are observable more frequently than those with the centers in the former half. The typical case is seen in the Example B 1, consequently the effect of this fact must also be taken into consideration, and the distribution pattern in the examples in which large schools are caught in the latter half should be more contagious than supposed on the results of the analyses and *vice versa*.

Moreover, both constants, P and ΔP, contain some accidental and computation errors, because they are estimated on the regression line of the catch rate on the lot number (each lot contains 50 consecutive baskets in this report) and especially the last lot containing less than 50 baskets is excluded from the estimation of the regression line. And this is more influential in the examples showing lower catch rates, although the estimated values in such examples are low and the observed values deviate so widely that sometimes the effect of the above-mentioned errors might be overcome by this deviation or the examples are put aside consideration because of

the expectation for large accidental errors, especially of the observed values. On account of the occurrence of these errors, the constants for the Examples B 17, B 19, Y 1, Y 5, A 19, A 21, A 29, A 31, A 32, A 37, A 38, A 39 and A 41 had to be re-estimated, because the estimated values in which the influence of the gradient is taken into consideration were shown incorrectly as if they were lower than the values in which the influence is put aside the consideration, the truth is, however, that the values taking the influence into consideration have to take theoretically higher values without regard to the direction of the gradients than those putting the influence aside the consideration.

In contrast with the formulae in which the influence of the gradients is taken into consideration, the formulae in which the influence of the gradients is put aside consideration are more or less rid of the errors due to the above-mentioned cause.

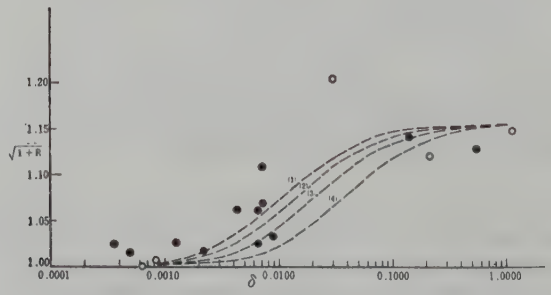


Fig. 20. $\delta - \sqrt{1+R}$ relation graph of big-eye tuna.
Note: Solid circle: δ is positive. White circle: δ is negative.
(1): M=400, (2): M=300, (3): M=200 and (4) M=100.

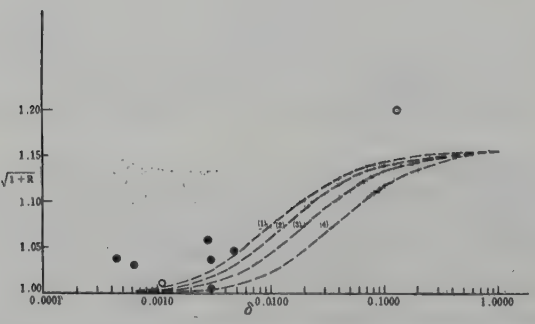


Fig. 21. $\delta - \sqrt{1+R}$ relation graph of yellow-fin tuna.
Notes are the same as in Fig. 20.

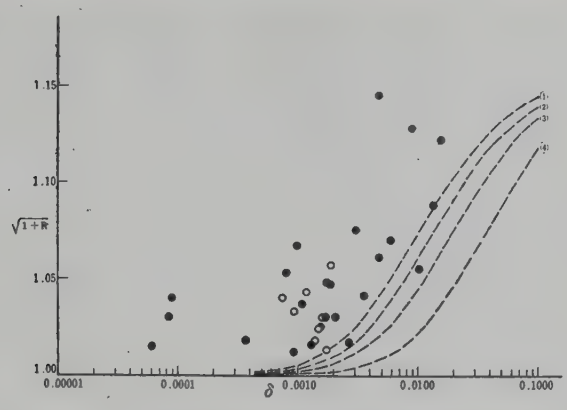


Fig. 22. $\delta - \sqrt{1+R}$ relation graph of albacore.
Notes are the same as in Fig. 20.

For this reason, in order to discuss upon the necessity of correcting the gradients in the corrected formulae which are considered to contain more accidental errors than the formulae in which the influence of gradients is put aside consideration, the relation between δ and square root of (corrected value / uncorrected value) at $k=0$ where the difference between both estimated values is the most pronounced was examined, as P and ΔP, consequently δ are represented as squares in the formulae. The results are shown in Figs. 20. 21 and 22. While, the corresponding rate can be estimated quite theoretically by the following procedures:

The corrected value : $\frac{mN(N-1)}{2} P_0^2 \left[1 + (m+1)\delta + (m+1)(2m+1)\frac{\delta^2}{6} \right]$

While the uncorrected value : $\frac{mN(N-1)}{2} \left(P_0 + \frac{m}{2} \Delta P \right)^2$

Set $\frac{\text{corrected value}}{\text{uncorrected value}} = 1+R$

$$1+R = \frac{1+(m+1)\delta+(m+1)(2m+1)\frac{\delta^2}{6}}{1+m\delta+\frac{m^2}{4}\delta^2}$$

and $$\left(\frac{3R-1}{12}m^2 - \frac{m}{2} - \frac{1}{6}\right)\delta^2 + (mR-1)\delta + R = 0$$

By substituting 400, 300, 200 and 100, for m, theoretical curves showing the relation between δ and the rate, (corrected value / uncorrected value), were pursued and they are also shown in these figures. If the computed values of the corrected formulae contain no computation error, the point should be located near the curve representing the relation at 400 baskets, but actually the computed values in these figures are higher than the theoretical ones, and this seems to indicate that the correction was made too much beyond the adequate degree. But two other examples of big-eye

tuna (Fig. 20), the same number of other examples of yellow-fin tuna (Fig. 21) and nine other examples of albacore (Fig. 22), in which the rate is lower than 1.00, are not included in these figures for the reasons mentioned already. This fact considered together, it may be said safely that the actually computed values are considered to be distributed at both sides of the theoretical curve representing the relation at 400 baskets. Then, the ratio, $\frac{(1+R_{comp.})-(1+R_{theor.})}{(1+R_{theor.})}$ should be taken into consideration [here $(1+R_{comp.})$ indicates the rate (corrected value/uncorrected value) actually computed, while $(1+R_{theor.})$ indicates theoretically estimated one], the numerator of this term indicates the computation error. Then it becomes clear that there are many examples in which the computation error exceeds the theoretical ratio. Moreover, it is also suggested, from these diagrams, that most of the actually computed values and theoretical ones are not so large, and this seems to indicate that it is unnecessary to make any corrections for the influence of the gradients when the degree of the deviation of the observed values from the estimated ones is considered together. But, before the correction of the influence of the gradient is accepted as dispensable, a little more consideration must be paid. And here the relation among the rate between the both estimated values, the number of baskets and δ (per basket) was examined theoretically more extensively. The results are represented in Fig. 23, which seems

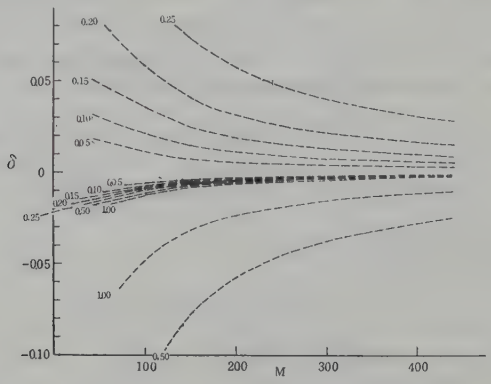


Fig. 23. Theoretical relation curves between M and δ.
Note : Numbers in the figure indicate various values of "R".

to show the following trends :

(1) Theoretical R does not exceed 0.15 at usual length ($300 < m < 400$) and at usual δ (smaller than 0.01).

(2) R never exceed 0.5 at any large δ.

(3) When $\delta < -0.05$, R is also smaller than 0.5.

(4) While, when $-0.003 < \delta < 0$, R increases sharply with decrease in δ.

(5) The highest R is expected at $-0.015 > \delta > -0.030$.

Accordingly, when it is requested to show the values in the corrected type more acculately, one or all of the following methods will bring the satisfactory results:

(1) Judging from the last two of the preceding terms, when δ takes a negative small value, the corrected values are computed better by replacing JP and P_0 by JP and $P_0(1+m\delta)$, respectively.

(2) To adopt one of the factor numbers of m as the length of lot for estimating the regression line is effective as the influence of the residual part is removed.

(3) Otherwise, at first estimate JP from the regression line, and then compute P_0 from the equation $N=\sum_{i=1}^{M}(P_0+iJP)$. (The constants in Examples B 17, B 19, Y 1, Y 5, A 19, A 21, A 29, A 31, A 32, A 37, A 38, A 39 and A 41 were re-computed by this method).

(4) Compute the corrected values by $(1+R_{theor.})\times$(uncorrected one).

3. Consideration upon the more advanced method —— 1. Interval method

As mentioned already in the section about the notes for decoding the diagrams, X(k) represents merely the theoretical number of the occurrence of the couples of individuals caught at the hooks spaced by k section-intervals (or hook-intervals), but the question concerning whether some intermediate hooks are occupied or not is left quite intact. Accordingly, the distribution pattern cannot be analyzed solely theoretically, but it is necessary to refer to the original records in which the occupied or intact states of respective hooks are shown in detail. For this reason, in order to make it possible to analyze quite theoretically, the following devices are proposed newly, in which the theoretical number of the individuals spaced by k intervals from the adjoining ones is represented.

1) Uncorrected form

Let us set that N individuals are caught at hooks scattered by chance along a row of gears, being constituted of m consecutive baskets of equal length and respectively with H hooks. By representing k as $k=a(H+1)+R$, separating it into the part divisible by the basket length and the remainder, the hooks spaced by k hook-intervals from respective hooks in the ith basket are shown in Table 4. Here a is a positive integer and varies from 0 to m, while R varies from 0 to H. Thus, when $R=0$, there are H hooks in the $(i+a)th$ basket spaced by k hook-intervals from respective hooks in the ith basket (i varies from 1 to $m-a$), but no hook is present in the $(i+a+1)th$ basket (i varies from 1 to $m-a-1$). On the other hand, the probability of the occurrence of individual at each hook is $P=\frac{N}{Hm}$, and the probability of both terminal hooks being occupied by individuals is P^2. And, there are $(aH-1)$ hooks between the both terminal hooks and the probability of the occurrence of the cases when the hooks are not occupied successively is Q^{aH-1}, here

$Q=1-P$. Consequently, the expected number of the individuals, the adjoining individuals of which are caught at the hooks spaced by k hook-intervals from the former, $\psi_{(k)}$, is represented as follows :

$$\psi_{(k)}=HP^2Q^{aH-1}(m-a) \quad \cdots\cdots (49)$$

By the same way as this, the formula applicable to at $R \neq 0$ is represented as follows:

$$\psi_{(k)}=P^2Q^{aH+R-1}(H-R)(m-a)+P^2Q^{aH+R-2}(R-1)(m-a-1) \quad \cdots\cdots (50)$$

That is to say, these formulae are obtained multiplying the theoretical value in the spacing method by the continuous product of the probability of the intermediate hooks being not occupied by fishes. Accordingly, the formulae of the interval method of the corrected types are represented as follows, here the details of the constructing process are omitted.

2) The formulae in which the influence of the gradient of the catch rate is taken into consideration ($H=4$)

R = 0

$$\psi_{(k)}=\sum_{i=1}^{m-a}\left\{(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4 \sum_{r=0}^{3}(Q-i\Delta P)^r(Q-\overline{i+a}\Delta P)^{3-r}\right\} \quad \cdots\cdots (51)$$

R = 1

$$\psi_{(k)}=\sum_{i=1}^{m-a}\left\{(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4 \sum_{r=1}^{3}(Q-i\Delta P)^r(Q-\overline{i+a}\Delta P)^{4-r}\right\} \quad \cdots\cdots (52)$$

R = 2

$$\psi_{(k)}=\sum_{i=1}^{m-a}\left\{(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4 \sum_{r=2}^{3}(Q-i\Delta P)^r(Q-\overline{i+a}\Delta P)^{5-r}\right\}+\sum_{i=1}^{m-a-1}\left\{(P_0+i\Delta P)(P_0+\overline{i+a+1}\Delta P) \prod_{b=1}^{a}(Q-\overline{i+b}\Delta P)^4\right\} \quad \cdots\cdots (53)$$

R = 3

$$\psi_{(k)}=\sum_{i=1}^{m-a}\left\{(P_0+i\Delta P)(P_0+i+a\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4(Q-i\Delta P)^3(Q-\overline{i+a}\Delta P)^3\right\} +\sum_{i=1}^{m-a-1}\left[(P_0+i\Delta P)(P_0+\overline{i+a+1}\Delta P)\prod_{b=1}^{a}(Q-\overline{i+b}\Delta P)^4\left\{(Q-i\Delta P) +(Q-\overline{i+a+1}\Delta P)\right\}\right] \quad \cdots\cdots (54)$$

$R=4$

$$\psi_{(k)}=\sum_{i=1}^{m-a-1}\left\{(P_0+i\Delta P)(P_0+\overline{i+a+1}\Delta P)\prod_{b=1}^{a}(Q-\overline{i+b}\Delta P)^4\right.$$
$$\left.\sum_{r=0}^{2}(Q-i\Delta P)^r(Q-\overline{i+a+1}\Delta P)^{2-r}\right\} \quad \cdots\cdots (55)$$

here $Q=1-P_0$.

3) The formulae in which the influence of the difference of the catch rate according to the depth is taken into consideration ($H=4$)

P_1 : catch rate of the hooks located at the shallower depth level.
P_2 : catch rate of the hooks located at the deeper depth level.
$Q_1=1-P_1$, $Q_2=1-P_2$

$R=0$

$$\psi_{(k)}=2(m-a)(Q_1Q_2)^{2(a-1)+1}(P_1^2Q_2+P_2^2Q_1) \quad \cdots\cdots (56)$$

$R=1$

$$\psi_{(k)}=(m-a)(Q_1Q_2)^{2a}(2P_1P_2+P_2^2) \quad \cdots\cdots (57)$$

$R=2$

$$\psi_{(k)}=2(m-a)(Q_1Q_2)^{2a}P_1P_2Q_2+(m-a-1)(Q_1Q_2)^{2a}P_1^2 \quad \cdots\cdots (58)$$

$R=3$

$$\psi_{(k)}=(m-a)(Q_1Q_2)^{2a}P_1^2Q_2^2+2(m-a-1)(Q_1Q_2)^{2a}P_1P_2Q_1 \quad \cdots\cdots (59)$$

$R=4$

$$\psi_{(k)}=(m-a-1)(2P_1P_2Q_1Q_2+P_2^2Q_1^2)(Q_1Q_2)^{2a} \quad \cdots\cdots (60)$$

4) The formulae in which the influences of both factors shown in sections 2 and 3 are taken into consideration ($H=4$)

$P_1+i\Delta P_1$: catch rate of the shallower hooks in the *ith* basket.
$P_2+i\Delta P_2$: catch rate of the deeper hooks in the *ith* basket.
$Q_1=1-P_1$, $Q_2=1-P_2$.

$R=0$

$$\psi_{(k)}=\sum_{i=1}^{m-a}\left[\left[\left[(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)\left\{(Q_1-i\Delta P_1)(Q_2-i\Delta P_2)^2\right.\right.\right.\right.$$
$$\left.\left.+(Q_2-i\Delta P_2)^2(Q_1-\overline{i+a}\Delta P_1)\right\}+(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)(Q_1-i\Delta P_1)\right.$$
$$\left.(Q_1-\overline{i+a}\Delta P_1)\left\{(Q_2-i\Delta P_2)+(Q_2-\overline{i+a}\Delta P_2)\right\}\right]$$
$$\left.\prod_{b=1}^{a-1}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\right] \quad \cdots\cdots (61)$$

R = 1

$$\psi_{(k)}=\sum_{i=1}^{m-a}\Big[(Q_1-i\Delta P_1)(Q_1-\overline{i+a}\Delta P_1)\prod_{b=1}^{a-1}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2$$

$$\Big\{(P_1+i\Delta P_1)(Q_2-i\Delta P_2)^2\ (P_2+\overline{i+a}\Delta P_2)+(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$(Q_2-i\Delta P_2)(Q_2-\overline{i+a}\Delta P_2)+(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)(Q_2-\overline{i+a}\Delta P_2)^2\Big\}\Big] \quad \cdots\cdots (62)$$

R = 2

$$\psi_{(k)}=\sum_{i=1}^{m-a}\Big[(Q_1-i\Delta P_1)(Q_2-i\Delta P_2)(Q_1-\overline{i+a}\Delta P_1)(Q_2-\overline{i+a}\Delta P_2)$$

$$\prod_{b=1}^{a-1}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big\{(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)(Q_2-i\Delta P_2)$$

$$+(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)(Q_2-\overline{i+a}\Delta P_2)\Big\}\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)\prod_{b=1}^{a}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big] \quad \cdots\cdots (63)$$

R = 3

$$\psi_{(k)}=\sum_{i-1}^{m-a}\Big[(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)(Q_1-i\Delta P_1)(Q_2-i\Delta P_2)^2(Q_1-\overline{i+a}\Delta P_1)$$

$$(Q_2-\overline{i+a}\Delta P_2)\prod_{b=1}^{a-1}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(P_2+i\Delta P_2)(P_1+i+a+1\Delta P_1)(Q_1-i\Delta P_1)$$

$$+(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)(Q_1-i+a+1\Delta P_1)$$

$$\prod_{b=1}^{a}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big] \quad \cdots\cdots (64)$$

R = 4

$$\psi_{(k)}=\sum_{i-1}^{m-a}\Big[\Big\{(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)(Q_1-i\Delta P_1)(Q_2-i\Delta P_2)$$

$$+(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)(Q_1-i\Delta P_1)\ (Q_1-i+a+1\Delta P_1)$$

$$+(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)(Q_1-\overline{i+a+1}\Delta P_1)(Q_2-\overline{i+a+1}\Delta P_2)$$

$$\prod_{b=1}^{a}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big] \quad \cdots\cdots (65)$$

Thus, the influence of the intermediate hooks being occupied or not is theoretically solved, although the values in which the influence of gradient is taken into consideration are practically too complex to compute and moreover considerable errors are expected during computation.

4. Further consideration upon the more advanced method —— 2. Analyzing method for the order of the arrangement of the intervals

There remains still another factor which might evoke a confusion when the trends deduced from the results of analyses are applied to those observable in the actually recorded pattern. This is the order of the arrangement of individuals spaced by the respective intervals.

That is to say, even when all individuals are scattered by chance along the row of gears, there may occur some successively arranged short intervals, besides some other successive short intervals are formed by the school formation and their actual number is naturally to be estimated. To solve this, the following method is proposed under the name of "arrangement analysis".

Let us set that N individuals are distributed by chance along a row of gears being constituted of m consecutive baskets. The total number of intervals between individuals is $(N-1)$, while the number of intervals as long as or shorter than k hook-intervals is $\sum_{k=1}^{k}\psi_{(k)}$.

Accordingly, the expected number of the occurrence of W consecutive intervals, each is equal to or shorter than k, $S_{(W.k)}$, is represented as follows:

$$S_{(W.k)}=\{P_{i(k)}\}^W\{Q_{i(k)}\}[2+(N-W-2)\{Q_{i(k)}\}] \quad \cdots\cdots (66)$$

here $\dfrac{\sum_{k=1}^{k}\psi_{(k)}}{N-1}=P_{i(k)}=1-Q_{i(k)}$.

Here, when $\psi_{(k)ob.}$ which is the actually observed $\psi_{(k)}$ is continuously higher than $\psi_{(k)theor.}$ which is $\psi_{(k)}$ theoretically computed at k from 0 to k_1, $S_{(W.k_1)}$ at respective W can be computed theoretically by substituting k_1 for k. The corresponding observed values, $S_{(W.k_1)ob.}$, can also be obtained from the original record. Accordingly, the number of schools being constituted of $(W+1)$ individuals is theoretically shown to be $\{S_{(W.k_1)ob.}-S_{(W.k_1)theor.}\}$.

It is, however, very doubtful if the accurate results can be obtained from these two series of analyses, because not only the estimation of $\psi_{(k)}$, consequently $S_{(W.k)}$

too, in which the influence of the gradient is taken into consideration, is very difficult, but also the computation errors are highly expected, together with the fact that $S_{(W.k)ob.}$ at respective W are considered not to be so large and accordingly accidental errors are fairly expected. Thus, here only the above-mentioned theoretical method to correct the errors assigned to the conception of $X_{(k)}$ is shown.

5. Consideration upon the factors affecting the gradient and the difference of the catch rate according to the depth

1) Consideration upon the factors affecting the gradient of distribution

In the operations, the setting of gears is begun with a certain station at about mid-night and ended in the other station spending 3 or 4 hours, then the boat is let drift for 3 hours or thereabout near the ending terminal of the gears, and the hauling of the gears is carried on in the counter direction, namely from the ending point of the setting towards the beginning point spending 12 hours or longer. Consequently, all the gears are soaked for *ca.* 3 hours at dawn, while the portion of gears near the starting point of the setting is soaked for about 6 times as long as the portion near the ending point.

Accordingly, at first it is set that the feeding activity is rather invariable through out the whole day. (1) When the fishes take baits after the hooks reach the settled levels, the increase of the catch rate is simply proportional to the soaking time; (2) but when the baits are taken while they are still sinking or contrarily on the way of the hauling at the shallower levels than the settled ones, the catch rate does not increase with the soaking time, but it is assumed to be rather constant. If it is assumed that most individuals are caught in the limited time, for example at dawn and dusk, as commonly recognized in many coastal and pelagic fishes, while in other time the probability of the occurrence of individuals at the hooks per unit time is very low and invariable and that the fishes take baits at only the settled levels; (3) When the setting of gears is begun at dawn after the fishes fed actively and the hauling is finished in dusk before the beginning of the active feeding, though such a case is hardly met with during the actual operations of professional boats, the catch rate is low throughout, but increases with the soaking time. (4) When the whole gears are set before the beginning of the active feeding at dawn and hauled up after the active feeding at dusk——such a case is considered to be frequently met with in the actual operations of professional boats——, the catch rate must be high throughout and show abrupt increases after a certain part of the gears. (5) If the whole gears are set before the beginning of the active feeding at dawn and hauled up before the beginning of the active feeding at dusk or the active feeding is missing at dusk, the catch rate may be pretty high and slightly increase with the soaking time. (6) When the setting of gears is begun after the active feeding at dawn is through or the active feeding is missing at dawn and the hauling of gears is finished after the active feeding at dusk, the catch rate is high only

near the last part of the hauling, but very low near the beginning parts. Now it is assumed that the baits are taken during the sinking or hauling up. (7) When the setting of gears is begun after the active feeding at dawn and the whole gears is hauled up before the beginning of the active feeding at dusk, the constant but extremely low catch rate may be observed throughout the whole row. (8) When the setting of gears is begun during the active feeding at dawn and the hauling is finished after the beginning of the active feeding at dusk, there must be shown the abruptly high catch rate at a certain part along the row, although the catch rate is pretty high throughout. (9) When the gears are set during the active feeding at dawn and wholly hauled up before the beginning of the active feeding at dusk, the catch rate may be kept uniformly without regard to the soaking time. (10) And when the setting of gears is begun after the active feeding at dawn and the hauling is finished after the active feeding at dusk, the catch rate is high only at the part being hauled up during the active feeding.

Here, in order to examine which of the above-mentioned cases is the most probable, the following consideration is made.

Set that the number of individuals caught in the *ith* basket from the beginning point of the hauling of the gears being constituted of m baskets is represented as $(P_0+i\Delta P)$. The number of individuals caught in the *0th* basket is P_0 and that in the last basket is $(P_0+m\Delta P)$. Further it is assumed that the catch rate increases with the soaking time.

$$P_0+m\Delta P=6P_0$$

Consequently $\Delta P=\frac{5}{m}P_0$

Further $\delta=\frac{\Delta P}{P_0}=\frac{5}{m}\fallingdotseq\frac{5}{400}=0.0125$

But δ in the actual examples is much lower than this, although δ is regarded as significant in most examples, except for those which contain only several individuals. This seems to suggest that the initial catch rate (this means the catch rate per unit time while the whole gears are soaked.) is relatively higher, and the catch rate does not increase in proportional to the soaking time and also that the catch rate is mostly not constant, but increasing slightly with the soaking time. Accordingly, the cases (2), (3), (6) and (10) and also (1), (7) and (9) are rejected. While, when the individuals are caught in the manner shown in cases (4) or (8), the population may be misregarded as containing 2 schools respectively located around the first basket and the parts hauled up after or during the active feeding at dusk (at or after the 260th basket), because the influence of the gradient is corrected on the assumption that the individuals are hooked in the manner shown in case (5) ; consequently the increase of the catch rate outside the time when the whole gears are soaked is simply proportional to the increase of the soaking time and this affects so as to smooth the abrupt increase of the catch. While, Figs. 7,9 and 11 examined in detail, it becomes clear that there are a considerable number of examples supporting the gradual increase of the catch rate or showing an intermediate grade between the

gradual and abrupt increases, but only a few examples clearly suggesting the abrupt increases. On the other hand, as there are many examples in which the existence of schools is recognized around the 250th basket, the existence of such schools was examined again carefully on Figs. 7, 9 and 11 on purpose to judge whether they are essential ones or attributable to that the basic assumptions are so different from the actual state. There are, however, scarcely any examples which are misregarded as containing a school around the 250th basket or the first one on account of regarding the abrupt increase of the catch as the gradual one. Accordingly, it seems not to be apart so far from the actual state to regard the increase of the catch rate as gradual, although to regard the catch increase as abrupt makes it easier to estimate the theoretical values in the interval method, consequently those of the arrangement analysis, in which the influence of the gradient of the catch is taken into consideration.

Next, there arises another question worthy to be examined carefully, what factors influence P_0. Here, P_0 is thought as the catch per basket during the time when the whole gears are soaked. Accordingly, the density of individuals, the duration of the soaking time and the lag of the time when the whole gears are soaked are considered to be strongly influential. Among these, however, the influence of the density, by which the total catch is determined, seems to be located aside the problem here treated

Table 11. Operation time, P_0/N and δ of respective operations (Big-eye tuna).

St.	Setting		Hauling		$\frac{P_0}{N}$	δ
	Begin	End	Begin	End		
1	23.47	03.40	06.31	21.42	0.001,26	0.007,084
2	23.40	03.20	06.30	21.54	−0.000,07	−0.216,079
3	23.31	03.02	06.40	19.50	0.001,21	0.008,958
4	23.37	03.13	06.27	19.30	0.000,03	0.543,507
5	23.30	03.05	06.57	20.25	0.001,25	0.007,107
6	23.30	03.05	06.40	20.11	0.001,24	0.006,625
7	23.48	03.27	06.30	21.53	0.001,60	0.004,288
8	23.45	03.28	06.30	19.35	−0.000,12	−1.272,854
9	23.50	03.28	06.38	21.54	0.002,59	0.000,488
10	23.44	03.24	06.21	20.03	0.003,32	−0.000,844
11	23.55	03.36	06.30	19.38	0.002,69	0.000,358
12	—	03.28	06.30	19.31	0.002,06	0.002,219
13	23.46	03.18	06.31	19.31	0.001,33	0.006,533
14	23.48	03.27	06.30	19.19	0.002,34	0.001,251
15	23.48	03.25	06.27	19.34	−0.000,62	−0.030,439
16	23.49	03.19	07.00	19.15	0.000,11	0.137,025
17	23.55	03.30	07.00	20.56	——	——
18	23.48	03.33	06.55	21.25	0.003,13	0.002,170
19	23.50	03.05	07.50	20.19	——	——

Table 12. Operation time, P_0/N and δ of respective operations (Yellow-fin tuna).

St.	Setting		Hauling		$\frac{P_0}{N}$	δ
	Begin	End	Begin	End		
1	23.47	03.40	06.31	21.42	——	——
2	23.40	03.20	06.30	21.54	0.003,51	−0.001,103
3	23.31	03.02	06.40	19.50	0.001,88	0.003,693
4	23.37	03.13	06.27	19.30	0.002,11	0.002,007
5	23.30	03.05	06.57	20.25	——	——
6	23.30	03.05	06.40	20.11	0.002,57	0.000,631
7	23.48	03.27	06.30	21.53	0.002,65	0.000,440
8	23.45	03.28	06.30	19.35	0.001,90	0.002,851
9	23.50	03.28	06.38	21.54	0.001,82	0.003,026
10	23.44	03.24	06.21	20.03	−0.000,13	−0.133,190

Table 13. Operation time, P_0/N and δ of respective operations (Albacore).

St.	Setting		Hauling		$\frac{P_0}{N}$	δ
	Begin	End	Begin	End		
1	03.20	08.00	11.00	03.10	0.003,76	−0.001,419
2	06.15	09.10	13.30	00.00	0.005,14	−0.001,771
3	03.35	07.00	10.25	01.00	0.001,94	0.002,701
4	03.25	07.15	10.30	00.30	0.000,72	0.015,591
5	03.32	06.45	10.30	00.30	0.002,07	0.001,541
6	03.40	05.10	10.55	01.40	0.002,88	−0.000,366
7	03.35	07.00	11.05	01.30	0.001,37	0.005,975
8	03.30	07.10	11.20	03.20	0.004,10	−0.001,909
9	05.00	08.20	13.05	01.20	0.001,23	0.010,197
10	04.00	07.40	11.05	01.00	0.003,73	−0.001,480
11	05.25	08.12	12.10	02.02	0.003,03	0.004,717
12	02.55	06.50	09.50	23.50	0.002,38	0.000,912
13	02.55	06.30	10.00	00.05	0.001,06	0.008,911
14	02.45	06.30	10.00	23.11	0.002,77	0.000,083
15	02.45	05.55	10.25	00.50	0.001,69	0.003,584
16	03.00	06.00	10.25	23.58	0.003,37	−0.000,930
17	02.53	06.18	10.04	03.00	0.003,29	−0.000,749
18	04.10	07.00	10.43	23.24	0.004,15	0.001,593
19	03.00	06.40	10.00	23.16	——	——
20	04.40	07.50	11.25	23.40	0.003,89	−0.001,176
21	02.50	06.30	10.00	23.20	——	——
22	02.55	07.50	10.55	23.43	0.002,63	0.000,964
23	03.45	07.13	10.00	23.28	0.001,99	0.002,076
24	02.50	06.24	10.20	01.30	0.002,73	0.000,061
25	03.15	06.42	09.50	23.43	0.002,20	0.001,299
26	02.40	06.40	09.50	23.55	0.002,47	0.000,803

27	02.50	06.20	09.50	23.55	0.001,48	0.004,839
28	02.50	06.30	10.00	01.20	0.001,84	0.003,051
29	02.50	06.20	10.08	23.46	——	——
30	03.00	06.30	10.00	23.25	0.002,18	0.001,672
31	02.50	06.40	10.00	23.00	——	——
32	02.45	06.30	09.50	23.30	——	——
33	02.50	06.30	09.55	00.28	0.002,31	0.001,115
34	03.30	07.10	10.32	00.30	0.002,19	0.001,749
35	03.00	06.30	10.25	00.55	0.002,15	0.001,889
36	03.10	06.25	10.23	23.40	0.002,77	0.000,088
37	02.55	06.10	10.10	01.05	——	——
38	03.05	06.30	10.02	23.25	——	——
39	03.05	06.30	10.15	00.05	——	——
40	03.25	06.50	10.25	23.20	0.000,82	0.013,670
41	03.25	07.00	10.57	00.37	——	——

consequently it is excluded in the following discussion. Accordingly, $\left(\frac{P_0}{N}\right)$ which indicates the catch rate per basket per individual of the total catch during the time when the whole gears are soaked, should be adopted in place of P_0. But the deviation of the duration and the lag of the time when the whole gears are soaked are very small in respective species [big-eye tuna, duration: 2 h 51 m — 3 h 52 m, beginning of the time when the whole gears are soaked: 03.02—03.40, ending of the same time: 06.21—07.00, yellow-fin tuna, duration: 2 h 51m—(3 h 30 m)—3 h 52m, beginning of the whole soaking: 03.02—03.40, ending of the whole soaking: 06.21—06.57, albacore, duration: 3 h 00 m —(4 h 00 m)—5 h 45 m, beginning of the whole soaking: 05.10—(07.00)—09.10, ending of the whole soaking: 09.50—(11.00)—13.30]. Moreover, any clear relation is not recognizable between the duration or lag of the time of the whole soaking and $\left(\frac{P_0}{N}\right)$. Thus, these can not be the factors influential enough to cause the large deviation of $\left(\frac{P_0}{N}\right)$ [big-eye tuna: $-0.000,62 \sim 0.003,32$, yellow-fin tuna: $-0.000,13 \sim 0.003,51$, albacore: $0.000,72 \sim 0.005,14$]. On the other hand, it is quite obvious that $\left(\frac{P_0}{N}\right)$ increases with the decrease in δ or $\frac{\Delta P}{N}$ because $1 = \sum_{i=1}^{m} \frac{P_0}{N} (1+\delta)$. Accordingly, if the factors influential upon $\left(\frac{P_0}{N}\right)$ are searched for, then the factors influential on δ must be also taken into consideration. Thus, the length of the time spent for the whole work from the setting to the hauling and the lag of the time about these works may be supposed to be influential. But either of them can not be the factors causing the large deviation of δ, because there is no clear relation between δ and them and moreover the deviation itself is relatively small as presumable from the discussions made about the factors influential upon $\left(\frac{P_0}{N}\right)$.

Besides the above-mentioned factors, the locality of schools is also very probably influential, because P_0 and ΔP are computed from the regression line of the catch within respective lots consisting each of 50 consecutive baskets on the lot number. But, none of the so clear relations can be obtained here, either. None of the environmental factors were found influential on P_0/N and δ, although the vertical distributions of the temperature and chlorinity were observed near the respective ending points of the setting of gears. And this is attributable to the following two causes: (1) the environmental factors near the ending point of the setting of gears can not be regarded as representing the environmental factors throughout the row of gears, because the observed environmental factors deviate so widely notwithstanding that the changes found in the locality and the date of observations and moreover the distance between the adjoining stations of observations are small as compared with the considerable length of the rows of gears that frequently the distance between certain parts within a single row might exceed that between adjoining rows, and (2) $\left(\frac{P_0}{N}\right)$ and δ are represented as the average values throughout the row, along which, however, a considerable variation can very probably be found in environmental factors.

2) Consideration upon the factors influential on the difference of the catch rate according to the depth

Many factors, such as the distribution of prey organisms, chlorinity, temperature, light intensity, duration of the sinking time of baits from surface to the settled depth

Table 14. Catch rates of hooks located at two different depth levels and temperature at 100 m and 150 m layers (big-eye tuna).

St.	Catch rate		Temperature (°C)	
	P_1	P_2	100 m	150 m
1	0.0495	0.1085	27.5	17.91
2	0.0546	0.0784	27.57	16.03
3	0.0396	0.0821	26.9	15.4
4	0.0298	0.0625	26.83	17.49
5	0.0587	0.1075	27.3	25.69
6	0.0655	0.1448	27.2	22.2
7	0.0497	0.0829	27.3	23.64
8	0.0208	0.0917	27.25	18.75
9	0.0875	0.1639	26.8	16.85
10	0.0465	0.1042	27.22	19.05
11	0.0391	0.0852	26.6	24.1
12	0.0299	0.0726	26.31	14.50
13	0.0297	0.0678	26.71	26.63
14	0.0337	0.0758	25.43	15.42
15	0.0420	0.1022	26.78	18.55

16	0.0377	0.0866	27.1	26.34
17	0.0432	0.0961	25.6	25.73
18	0.0905	0.1992	25.65	16.55
19	0.0726	0.1420	25.85	15.9

Table 15. Catch rates of hooks located at two different depth levels and temperature at 100 m and 150 m layers (Yellow-fin tuna).

St.	Catch rate		Temperature (°C)	
	P_1	P_2	100 m	150 m
1	0.0357	0.0852	27.5	17.91
2	0.0686	0.0812	27.57	16.03
3	0.0645	0.0660	26.9	15.4
4	0.0369	0.0540	26.83	17.49
5	0.0182	0.0223	27.3	25.69
6	0.0320	0.0292	27.2	22.2
7	0.0331	0.0345	27.3	23.64
8	0.0319	0.0375	27.25	18.75
9	0.0292	0.0319	26.8	16.85
10	0.0155	0.0141	27.22	19.05

Table 16. Catch rates of hooks located at two different depth levels and temperature at 100 m and 150 m layers (Albacore).

St.	Catch rate		Temperature (°C)	
	P_1	P_2	100 m	150 m
1	0.0393	0.0772	22.62	(20.60)
2	0.1080	0.1300	21.70	(18.50)
3	0.0914	0.1386	22.40	(20.40)
4	0.0811	0.1108	22.50	(22.39)
5	0.0868	0.1079	21.90	(21.08)
6	0.0553	0.1053	20.83	20.98
7	0.0694	0.0833	21.62	22.50
8	0.0709	0.1289	22.60	21.46
9	0.0433	0.1122	22.20	21.51
10	0.0986	0.1392	21.42	21.43
11	0.0380	0.0802	21.86	21.40
12	0.0537	0.0730	22.65	20.14
13	0.0307	0.0842	22.35	21.72
14	0.0205	0.0642	22.50	21.80
15	0.0385	0.0687	22.61	22.45
16	0.0300	0.0817	21.25	20.72
17	0.0178	0.0219	22.20	20.98
18	0.0212	0.0348	22.49	22.09
19	0.0319	0.0485	22.40	21.12
20	0.0273	0.0485	——	——

21	0.0481	0.1126	21.00	20.08
22	0.0636	0.1185	20.50	19.60
23	0.0541	0.0770	20.62	20.01
24	0.0435	0.0734	20.20	20.00
25	0.0486	0.1000	——	——
26	0.0365	0.0608	20.07	19.52
27	0.0490	0.1035	21.70	20.25
28	0.0327	0.0749	20.96	19.81
29	0.0396	0.0710	20.12	20.43
30	0.0333	0.0722	19.50	17.90
31	0.0235	0.0497	21.46	20.38
32	0.0150	0.0874	20.85	20.68
33	0.0324	0.0500	21.00	20.38
34	0.0374	0.0609	21.80	20.82
35	0.0278	0.0750	21.90	20.92
36	0.0203	0.0595	21.41	21.31
37	0.0464	0.0970	21.00	20.40
38	0.0230	0.0797	21.05	20.37
39	0.0152	0.0665	20.93	20.20
40	0.0365	0.0955	25.40	23.50
41	0.0486	0.0811	23.80	24.50

Temperature enclosed in parentheses indicates that of 200 m layer.

etc., differ according to the depth. It is very probable that the vertical difference of the catch rate may be caused by certain factors which may differ markedly between the levels of shallower and deeper hooks at the stations showing large vertical difference of the catch rate, but not at the stations where the vertical difference of the catch rate is very small. Temperature, one of the actually observed factors, seems to satisfy the above-mentioned conditions. The temperature does not vary so conspicuously in the upper layer shallower than 100 m or in the lower layer deeper than 200 m, while it varies prominently near the level of 150 m, which shows the approximate situation of the thermocline in the surveyed fishing grounds. No clear relation is recognized, although the following trends are seen somewhat clearly. In respective species, the catch rates of the deeper hooks increase with those of the shallower hooks keeping the following relations:

Big-eye tuna : $P_2 = 1.9P_1 + 0.01$

Yellow-fin tuna : $P_2 = 1.25P_1 + 0.005$

Albacore : P_2 increases with P_1, but the deviation is rather large.

Here P_2 is the catch rate of the deeper hooks, while P_1 is that of the shallower hooks. Accordingly, however large or small ($P_2 - P_1$) may be, $\frac{P_1}{P_2}$ is rather constant, consequently the ratio, estimated value in which the influence of the difference of catch rates is taken into consideration by that putting aside the con-

sideration is rather invariable regardless of the degree of the difference between them. And this seems to make it difficult to find out the factors influential upon the vertical difference of the catch rate. Besides, it was also cleared that the catch rate of yellow-fin tuna at both shallower and deeper hooks increased with the decrease of temperature at 150 m deep, and this suggests that the deeper the thermocline is, the wider the fishes are scattered in the thicker layer, consequently the catch rate is lowered.

Appendix

Application of the method proposed in this paper to the analyses of the data obtained by the different fishing methods

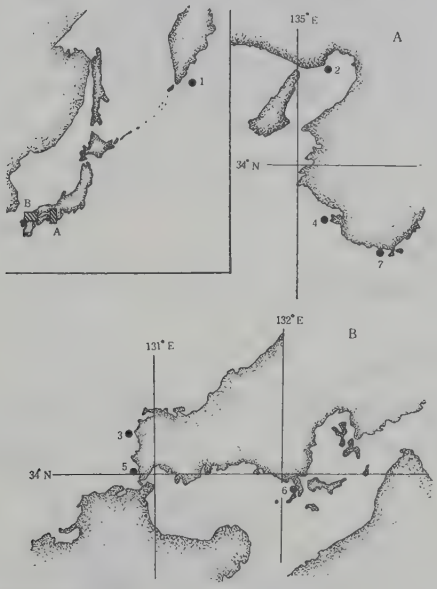


Fig. 24. Sketch chart showing the stations where the examples analyzed in the chapter "Appendix" were obtained.

Note 1: East of Cape Lopatka (Salmons caught by gill-net).
2: Off Kobe Harbour (Squids fished by squid-traps).
3: Off Yatama (Squids angled under the fish-gathering lamp).
4: Off Seto Marine Biological Laboratory (*Parapristipoma trilineatum* and *Leptscolopsis nagasakiensis* angled under the fish-gathering lamp).
5: Off Shimonoseki College of Fisheries (*Chrysophrys major* and *Fugu rubripes* angled in the day time along the shore).
6: Off Tana (*Muraenesox cinereus* caught by long-line).
7: Near the Cape of Shionomisaki (*Gymnothorax kidako* and *Epinephelus fario* fished by long-line).

1. Application to the analyses of the salmon population caught by gill-net

The salmon off shore fishery of mother-ship type has been re-opened since 1952, and fortunately, I had an opportunity to gather the data of the distribution of fishes on gill-nets in the end of the first fishing season, from the 20th to the 22nd of July,

1952, on board the Hôsyô-maru No. 3, one of the surveying ships of the Nippon Suisan Co. Ltd., at about 100 miles east of Cape Lopatka. One hundred and twenty-eight or nine sections of net, each *ca.* 40 m long, 7.5 m deep and with meshes of about 15. cm sq., were united in a straight series and set in the direction of SSW from a certain fishing station at about 6 p.m. in the evening. The hauling of nets was begun at about 5 a.m. and it took about 4 hours to finish the work. The results of the analyses of the distribution pattern obtained by using MORISITA'S method was already published (MAÉDA, 1953), but here a brief discussion is given after the values are converted into the values computed by formulae (1) and (2), in this case one section is adopted as the unit length; the results are shown in Figs. 25 (1) and (2).

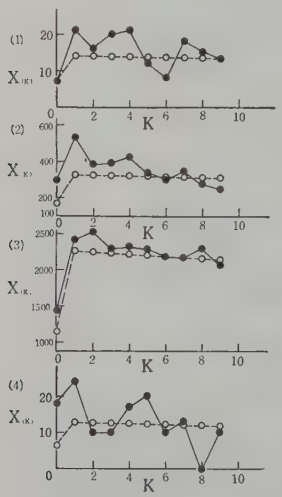


Fig. 25—1. X(k)—k relation diagram of salmons caught by gill-net (July 20—21, 1952).
Notes: (1) *Oncorhynchus nerka* (2) *O. keta* (3) *O. gorbuscha* (4) *O. kisutch.*

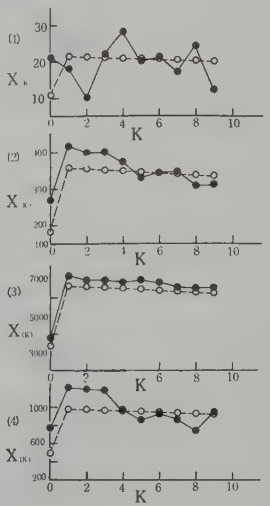


Fig. 25—2. X(k)—k relation diagram of salmons caught by gill-net (July 21—22, 1952).
Notes are the same as in Fig. 25—1.

From these figures, it becomes clear that each of salmon species shows rather specific distribution pattern, although all the species were caught mingled with one another on the same row of gill-nets at the same operation. Namely, *Oncorhynchus gorbuscha* are distributed forming wide, but very weakly contagious schools covering 6 sections or longer. Next, *O. keta* forms a pretty conspicuous, but slightly narrower schools covering 4 or 5 sections. While the populations of *O. nerka* and *O. kisutch* are constituted each of rather strongly contagious but narrow schools, although it is difficult to give any definite conclusions because of the scarcity of caught individuals and of analyzed examples.

2. Application to the analyses of the squid population caught by squid-traps

In the Inland Sea of Japan and the adjacent waters, a quantity of squids, *Sepia esculenta* HOYLE and *Sepiella japonica* SASAKI, are caught in winter or early spring by the somewhat strange fishing apparatus——series of traps set on the bottom of the shallow waters. The distribution pattern in these catches is analyzed here. On the other hand, like other squids, *Ommastrephes sloani pacificus* STEENSTRUP and *Onychoteuthis banksii* (LEACH) in the northern waters, *Doryteuthis kensaki* (WAKIYA et ISHIKAWA) and *D. bleekeri* KEFERSTEIN are caught at night in late spring or early summer by angling under the fish-gathering lamp, and the distribution of the time when the squid is angled will be analyzed in next section.

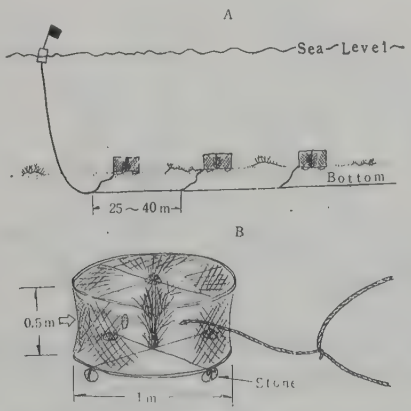


Fig. 26. A model of the squid-trap.
A. Schema showing the way of operation.
B. Structure of a trap.

The outline of gears is shown in Fig. 26, but the details differ more or less according to districts. Usually, twenty to forty traps are united into a series and set on the bottom at the beginning of the fishing season. And they are hauled up every one day to collect captured squids. The data recording the number of squids caught by respective traps of 4 series of gears on June 1st, 1955 near Kôbe Harbour were offered to my disposal by courtesy of Mr. T. FUMOTO of Kôbe University and now analyzed by using formulae (1) and (2), here the average interval between adjoining traps is adopted as the unit length.

The result of the analysis of Example 1 which is constituted of 17 individuals caught by 40 traps is represented in Fig. 27—(1). This suggests that the population seems to be constituted of many strongly contagious schools covering one trap and being spaced by 2-trap intervals, besides a few wider ones covering about two traps,

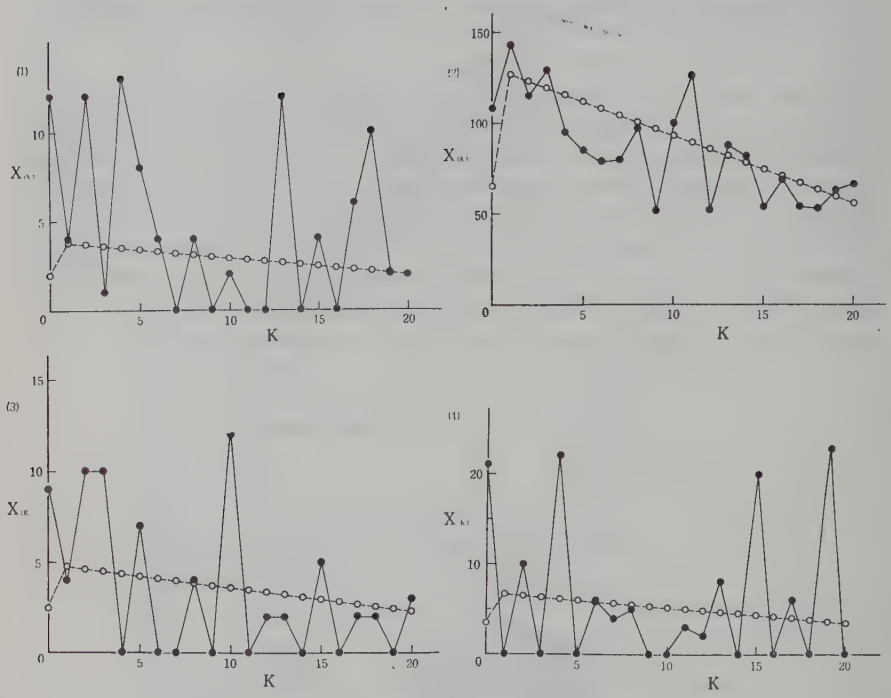


Fig. 27. X(k)—k relation diagrams of squids caught by squid-traps.
Note: Number enclosed in parentheses indicates the number of example.

although the scarcity of the total catch may introduce some accidental errors. While in Example 2 shown in Fig. 27—(2), the catch rate is 4 times as high as in Example 1 (68 individuals were caught by 35 traps) and here the schools seem to be less contagious and wider than those of Example 1. In Figs. 27—(3) and 27—(4) showing the results of Examples 3 and 4 in which the catch rate is as low as in Example 1 (Example 3 : 14 individuals were caught by 37 traps, Example 4 : 17 individuals were caught by 40 traps), the distribution pattern is nearly the same as that of Example 1.

3. Application to the analyses of the distribution pattern of the time when squids are angled under the fish-gathering lamp

In all examples concerning tunas, salmons and squids, the formulae were used to analyze the distribution pattern in space. But here the proposed method is used to analyze the time correlation.

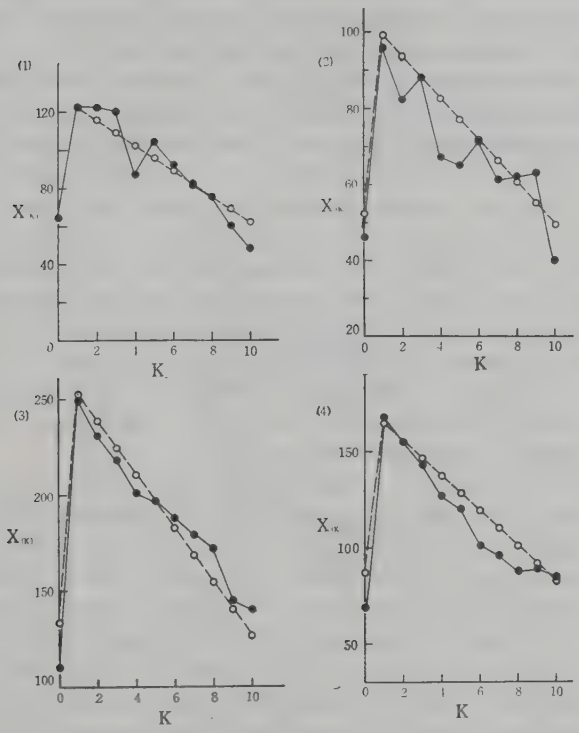


Fig. 28. X(k)—k relation diagrams of squids angled up under the fish-gathering lamp.
Note: Numbers in parentheses are representing the number of respective fishermen.

In treating of many examples in fisheries suitable for the analyses of the time distribution, the distribution of the time when fishes are angled during one operation is taken up in order to fit the order of the time analysis to that of the above-mentioned examples in which the spatial distribution within one operation is analyzed, although there is no way to convert the space into the time. On the other hand, in order to get the results containing less accidental errors, it is very desirable to analyze the data obtained by the angling of the fishes which are caught in abundance within a limited time. The squid angling, analyzed here, seems to be one of the examples most suitable for this purpose.

The records shown here were obtained off Yatama, near Shimonoseki, during the short period from 20.51 to 22.30 on June 2nd, 1955 by 4 fishermen on board the training boat No. 15 of our college. Fishermen No. 1 and No. 2 occupied their seats from stem to stern on the starboard, while Fishermen No. 3 and No. 4 sat on the port side. The gears were equipped with mimetic artificial preys and a fish-gathering lamp of

1 kw was put at the end of the over-hang of 1 m long at the middle on each side after it became quite dark. The catches by respective fishermen were recorded at every unit time of five minutes just since the light was put on.

If the density or the feeding activity of the squids under the light deviates prominently within an operation —— for example, small schools gather to lamp one after another, while most individuals of a certain school are caught before the next school comes there, or large schools pass through one by one staying under the light for a short time —— then the correlation coefficients among the number of individuals caught by respective fishermen in each unit time (5 min. in this report) have to take significant positive values and all the diagrams showing the contagiousness of the time of the fishes being angled should indicate the similar pattern. However, all correlation coefficients obtained actually, except for that between Fishermen No. 1 and No. 2, take low and insignificant values, moreover, the diagrams of the time contagiousness do not indicate the same pattern, despite of the fact that all fishermen were on board the same boat during the said period, consequently always the same population was fished by these four fishermen.

Besides, it is also alluded to in the diagrams that the most skillful fisherman, No. 3, angled squids at the self-spacing time intervals throughout the whole operation. The next veteran fisherman, No. 4, angled also at the self-spacing time intervals, although the correlation coefficient between the number of individuals caught by Fishermen No. 3 and No. 4 is insignificant. While the pattern assumable from the catches of the third fisherman, No. 1, shows quite a different feature which indicates the appearance of two schools, one was maintained for 20 minutes and the other appeared about 40 minutes later, but stayed there longer. And the diagram based on the catches by the last fisherman, No. 2, alludes to the appearance of several schools, although generally seeing the squids were angled up by him at the self-spacing time intervals.

Further, it is assumable that Fishermen No. 3 and No. 4 are skillful enough to angle up a quantity of squids even when the density is considerably low, but it requires at least 1 minute to haul up the caught squid, take it off the gear and set the gear again at the adequate depth, thus they can get squids at nearly constant time intervals, but never get more than 5 individuals within 5 minutes however high the density of squids may be. Fisherman No. 1 is not so skillful as them, but yet he is able to angle up many individuals when the density is higher. Fisherman No. 2 is considered not to be so skillful as Fishermen No. 3 and No. 4 but somewhat better than No. 1 at the angling under the lower density, though he can not do every treating so quickly as No. 1 even when the schools are under the light.

4. Application to the analyses of the distribution pattern of the time of the benthonic fishes being angled under the fish-gathering lamp

While waiting for small fishes assembling so densely under the light enough to be hauled by net, not only the pelagic fishes but also some benthonic ones are angled under the light. As an example of the above-mentioned cases, the results of the analyses, by using the formulae (1) and (2), on the records obtained during the period from August to September in 1950, when the food relation and several phenomena closely related with it were studied about the temporal community assembling under the light, are shown below:

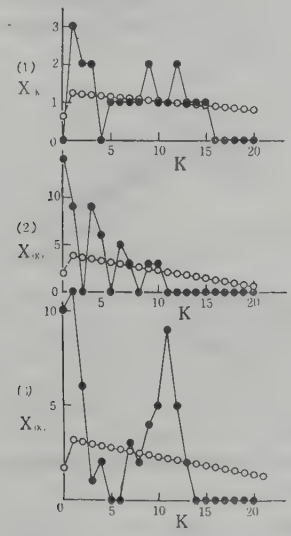


Fig. 29. X(k)—k relation diagrams of the angled time of benthonic fishes under the fish-gathering lamp.
Parapristipoma trilineatum (THUNBERG)
(1) Aug. 16, 1950. (2) Aug. 25, 1950 (3) Sept. 17, 1950.
Note: Theoretical values are estimated by formulae (1) and (2), in which the unit interval is 5 minutes.

The distribution pattern of the time of *Parapristipoma trilineatum* (THUNBERG) being angled is shown in Fig. 29. No discussion is made for Example 1, because considerable accidental errors due to the scarcity of the catch can be expected. While Example 2 suggests the appearance of 4 patches at 15 minutes intervals during the operation and the population of Example 3 seems to be constituted of 2 strongly contagious schools being spaced *ca.* 50 minutes from each other. Figure 30 representing the distribution patterns of the angled time of *Leptscolopsis nagasakiensis* (TANAKA) shows that the appearance of 4 less contagious patches is assumable during the operation of Example 1, the catch in Example 2 seems to be constituted of a single patch maintained so long but of such weak contagiousness that it can be regarded as a bundle of several shorter visits and the population in Example 3 shows quite the same feature

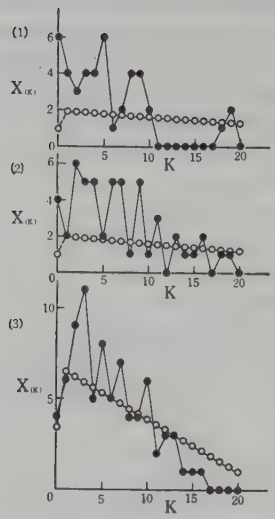


Fig. 30. X(k)—k relation diagrams of the angled time of benthonic fishes under the fish-gathering lamp.
Leptscolopsis nagasakiensis (TANAKA)
(1) Aug. 16, 1950. (2) Aug. 22, 1950 (3) Aug. 25, 1950.
Note: Theoretical values are estimated by formulae (1) and (2), in which the unit interval is 5 minutes.

as that of Example 2, although this cannot be considered to be free from accidental errors due to the scarcity of the catch.

5. Application to the analyses of the distribution pattern of the time when the fishes are angled in the day time along the shore

Here, the results of the analyses on the records of the day time angling by using formulae (1) and (2) are presented in Fig. 31 in a hope that it might be useful to understand the problem under the consideration. It is suggested that the catch of pogy, *Chrysophrys major* (T. et S.), is considered to be constituted of a single long visit of such weak contagiousness that it may be subdivided into 3 or 4 shorter visits; while the population of puffer, *Fugu rubripes* (T. et S.), seems to be constituted of 4 less contagious visits appeared regularly at 20-minute intervals.

6. Application to the analyses of the distribution pattern of benthonic fishes hooked along the coastal long-line

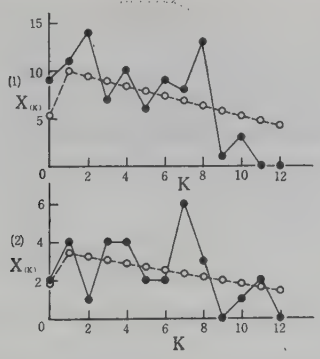


Fig. 31. X(k)—k relation diagrams of the angled time of benthonic fishes in the day time along the shore not so far from Shimonoseki College of Fisheries.
(1) *Chrysophrys major* (T. et S.)
(2) *Fugu rubripes* (T. et S.)
Note: unit interval is 5 minutes. Records during the period from 09.18 to 10.53, Sept. 12, 1955.

Since the old-time, the coastal long-line has been one of the most important fishing methods for Japanese fishermen living on the fisheries of a small scale along the coast and a considerable part of the catch in the coastal waters, especially from the benthonic layers, are got by this method. Accordingly, the distribution pattern of the fishes observed in the catches of this fishing method is quite worthy to be studied as well as that of the off-shore fisheries from the economical point of view. The gears for this fishery are, however, set respectively in a meandering course through the places to places which are regarded as good fishing spots by fishermen on their experiences and usually very limited —— only a few meter in width, consequently the probability of the occurrence of fishes in respective parts along the row of gears cannot be considered to be compatible with the basic assumption of the proposed formulae and it is very probable that the dishomogeneity of the probability of the occurrence of individuals assigned to the environmental difference may frequently be misregarded as the distribution pattern shown by the fishes themselves. For these reasons, only a few of abundant examples are quoted in the followings.

Figure 32 represents the distribution pattern of a sea-eel, *Muraenesox cinereus* (FORSKÅL), along the long-line, here the theoretical values were computed by formulae (5) and (6). The theoretical values at $k=a(H+1)$ are $H/(H-1)$ times the values at $k=a(H+1)-1$ or $k=a(H+1)+1$ (here, H is the number of hooks attaching to each basket and a is a positive integer) just like the theoretical values computed about the tuna long-line. For the gears such as the sea-eel long-line with so large H, it seems unnecessary to correct the influence of the existence of the buoy lines, because $H/(H-1)$ is not so far from 1 as compared with the deviation of the observed values. Although most of the observed values are a little higher

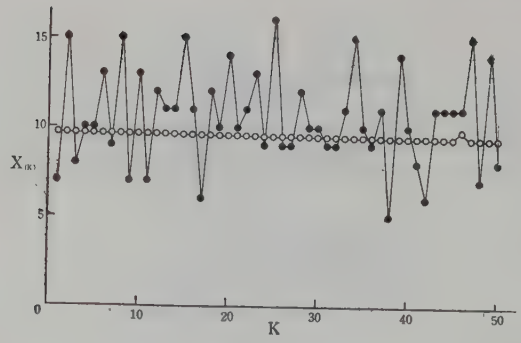


Fig. 32. X(k)—k relation diagram of *Muraenesox cinereus* (FORSKÅL).
Note: One hundred and twelve individuals were caught on Sept. 5, 1955 off Tana near Hiroshima, by the gears consisting of 29 baskets respectively with 45 hooks.

than the estimated ones and this seems to indicate that sea-eels are distributed contagiously covering more than one basket, yet this fish may be regarded as one of a few fishes of which the couples of individuals caught at the adjoining hooks are less than those in the chance distribution; anyhow some accidental errors are expected as the observed and estimated values are very low. The above-mentioned phenomena can be regarded as reflecting a certain habit of sea-eel, namely it is an active piscivore and possibly shows territoriality, consequently the fishes distribute being spaced more evenly than in the chance distribution.

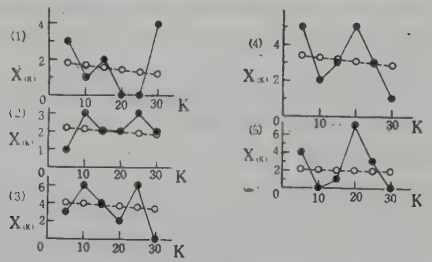


Fig. 33. X(k)—k relation diagrams of benthonic fishes caught by the coastal benthonic long-lines.
(1) *Epinephelus fario* (THUNBERG), Aug. 14, 1955.
(2) *Gymnothorax kidako* (T. et S.), Aug. 18, 1955.
(3) *E. fario*, Aug. 18, 1955.
(4) *G. kidako*, Aug. 20, 1955 (each basket with 80 hooks).
(5) *E. fario*, Aug. 20, 1955 (each basket with 80 hooks).
Note: The original records were obtained near the Cape of Shionomisaki, by the long-line consisting of 2 baskets each having 40 hooks and set on the bottom.

Figure 33 shows the examples of the distribution patterns of fishes caught by the

benthonic long-line near the Cape of Shionomisaki and in which both observed and estimated values are counted at each of five consecutive k. As the influence of accidental errors due to the scarcity of the catch can be expected, no further discussion is made other than the following. The distribution patterns of *Gymnothorax kidako* (T. & S.) and *Epinephelus fario* (THUNBERG) caught by the same row of gears take the similar feature, but at least partly this might be a strange coincidence, for the correlation coefficients computed between them in the examples observed on August 18 and 20, 1955 are -0.181 and -0.167 and this suggests that both species are distributed independently of each other.

Summary and Conclusions

It is regarded as a part of the fields unexplored but with the basic importance in fisheries ecology to study the most detailed distribution pattern of tunas along the row of long-line, because this may offer some theoretical bases for various technical problems and at the same time some clues for several biological phenomena. But there are a few papers worked on the distribution of individuals along the row of long-line, whereas much efforts in the field of commercial fisheries and in the studies on the distribution of tunas have been made to find out some better fishing grounds, this can be regarded as the distribution pattern in a much greater scale. Actually it is practically impossible to carry out any direct experimental methods for the analyses of the distribution pattern of tuna along the long-line, because the tuna population fished by the long-line is situated approximately at the layer deeper than 100 m and moreover the length of a row reaches beyond 50 km. Therefore, it seems to be most effective to use some indirect methods adopted for the analyzing of the insect population in order to analyze the distribution pattern of tunas along the long-line. The analyses of the most detailed distribution pattern by using the indirect theoretical methods may be recognized as a new unexplored branch in fisheries ecology.

For the purpose of clarifying the distribution pattern, the frequency distribution of individuals caught in respective sections is usually examined and compared with some theoretical ones. But this method is lacking in the consideration upon the spatial relation among respective sections. To fill up this deficiency, it is recommended to adopt some other methods in which the distribution along the row of long-line is treated individedly as a continuous one. On this standpoint, the works of MURPHY and ELLIOT (1954) and MORISITA (1950, 1954 a, 1957 and M. S.) should be appreciated very highly. But the method adopted by MURPHY and ELLIOT, as well as correlogram, seems not to be available to the examples in which the catch rate increases with the soaking time, moreover the results are misregarded as less contagious than actual on account of the influences of the following 4 factors: (1) some hooks may be occupied by other fishes, (2) the existence of buoy lines, (3) all hooks are not set at the same depth level and (4) for instance the potential sequence of a certain species is broken since other species of tunas or fishes thieve the baits. Strictly speaking, MORISITA'S method, one of the spacing methods, is also unsuitable because of the same reason.

Thus, in order to analyze the distribution pattern of individuals along the long-line, it is indispensable to establish some new formulae in which the influences of the above-mentioned factors are taken into consideration.

The outline of the history of the tuna long-line fishery and the studies on tuna is given briefly. The papers treating of the distribution are classified into two groups: one comprises those in which the frequency distribution of the number of individuals caught within a relatively small section is examined for the purpose of studying the

social habits or the mechanism of dispersal, while the other includes those in which the frequency distribution of the number of individuals or the amount of the catch within a rather large section is examined as a preliminary procedure of some other statistical treatment. Several of the former group chiefly treating of the distribution of terrestorial animals, especially insects, are presented. Concerning the latter only an example showing the frequency distribution of the catch per unit effort in various fishing methods is presented.

Generally the chapter "method and material" should include the detailed descriptions of the method used in the paper, but the method itself, the processes of the analyses, proposed in this paper is one of the principal subjects of this report as important as the results and thus it is excluded from the chapter which contains only the outline of the fishing method and the sources of the analyzed records.

Some preliminary consideration was given to the guessing of the existence of schools wider than the whole length of a row of gears, because the width of schools discussed in this report never reaches beyond the whole length of a row of gears.

The basic assumption of the theoretical distribution is set as the distribution is a chance one, because there is no evidence supporting the schooling habit of tunas living in the deeper layers of the ocean, whereas there are known many facts which seem to support their solitary life. And the formulae were constructed to be used under respective conditions mentioned below:

Sphere of application	Unit length	Factors, the influences of which are taken into consideration	Formulae
applicable to all serial gears	divisible by one basket (or section) length	none	(1) & (2)
		gradient of catch rate	(3) & (4)
applicable only to the long-line	hook-interval	none	(5) & (6)
		gradient of catch rate	(7) & (8)
		difference of catch rate according to depth	(9)～(13)[H = 4]
			(14)～(19)[H = 5]
		both of the above-mentioned factors	(20)～(24)[H = 4]
			(25)～(30)[H = 5]

Note : Formulae (1) and (2) were obtained from MORISITA'S formulae, while the others were newly established.

The analyses of Series I were carried out to catch the outline of the distribution pattern projected along the row of long-line, where the formulae (1)～(4) were used and 5 consecutive baskets were adopted as the unit length. In another series of analyses, one basket was used as the unit length in formulae (1)～(4). Besides the

above-mentioned two, still another series of analyses was tried by using formulae (5)～(13) and (20)～(24) in which the unit length was made as short as possible, namely a single hook-interval was adopted, because it was considered to be very significant to clarify the elemental structure not only from the ecological but also from the technical point of view.

To make it easier to read the diagrams showing the results of the analyses, several notes were given in the section "Notes for decoding the diagrams and notation used in them".

Nineteen examples of big-eye tuna were analyzed and the results are shown in Fig. 8 which indicates that the extremely strong contagiousness of the catch between the adjoining hooks is one of the characteristics of the distribution pattern of this fish. Concerning the problems whether large schools are observable or not and whether the distribution pattern is contagious or self-spacing, no definite answer is obtaind, although about a half of examples alludes to the existence of large schools and 1/5 of examples shows the self-spacing pattern. However, generally speaking the individuals are thought to be distributed almost by chance.

The results of the analyses of ten examples of yellow-fin tuna are illustrated in Fig. 10. There are some examples, in which it is very difficult to deduce the outline of the distribution pattern, especially from Series Ⅲ, because the catch rate is very low consequently many accidental errors are expected and both the observed and estimated values are very low. Only the following trend can be regarded as a general feature : the difference between the two series of the estimated values, in one of which the influence of the difference of the catch rate according to the depth is taken into consideration, while in the other this influence is put aside the consideration, is very small and the similar trend can be seen concerning the influence of the gradient, although it is very probable that this is more or less attributable to the computation errors, especially those of constants due to the lower catch rate. The distribution as a whole is not apart so far from the chance distribution. Some grade of contagiousness of catch is observable between the adjoining hooks, although it is not so strong as that of big-eye tuna. It seems to be one of the characteristics of the distribution pattern of this species that there are some elemental clusters covering the width longer than 1～2 baskets, but this may be more or less due to the low catch rate, too.

The examples of albacore was increased up to 41, because the school formation is highly probable in this species as a considerable amount of younger individuals are caught by angling. But the essential pattern does not differ so much from those of big-eye tuna and yellow-fin tuna, *i.e.*, the grownups are roughly said to be distributed almost by chance. Contrary to the expectations that the school formation is highly probable, about 1/3 of examples showed the self-spacing pattern, although about a half of examples showed the contagious pattern. And it may be regarded as one of the characteristics of the distribution pattern of this species that no clear contagious pattern is observable within a short range in contrast with the cases of big-eye tuna

and yellow-fin tuna (Fig. 12).

On the other hand, the relation among the localities of hooked individuals belonging to different species is also worthy to be analyzed as well as that found in the same species, because this problem is very interesting to ecologists, too. And the formulae were constructed to represent the expected number of individuals of a certain species (Species A) observable in the sections spaced by k section-intervals from the respective sections occupied by the individuals of another species (Species B) under the condition that both species are distributed independently of each other. This was made by summing the two formulae, in one of which the probability of the catch in the ith section or at each hook in the ith section in the spacing formulae was replaced by that of species A and those in the $i+kth$ and $i+k+1th$ (or $i+ath$ and $i+a+1th$) were replaced by those of Species B, while in the other *vice versa*, otherwise by subtracting (the expected number in the case when the population was constituted of Species A only) and (the expected number in the case when the population was constituted of Species B only) from (the expected number in the case when the population was constituted of Species A and B). That is to say, the correlation formulae corresponding to respective spacing formulae are as follows:

Spacing formulae	Correlation formulae
(1) & (2)	(31) & (32)
(3) & (4)	(33) & (34)
(5) & (6)	(35) & (36)
(7) & (8)	(37) & (38)
(9) ~ (13)	(39) ~ (43)
(20) ~ (24)	(44) ~ (48)

It is a well known fact as to the geographical distribution of the three species of tunas, that the yellow-fin tuna is living in the region of lower latitudes, next comes the big-eye tuna and albacore is distributed in the higher-latitudinal area. But yet a small number of individuals of other two species are usually caught by the same row of gears mingled with abundant individuals of a predominant species. Thus arises a question whether the individuals of the subordinate species join to the school of the individuals of the predominant species or are distributed independently of or repulsively to the latter. To clarify this problem, the relation between the localities of hooked individuals of big-eye tuna and yellow-fin tuna was analyzed on 10 examples. The results are shown in Fig. 13 which indicates the following tendencies: generally speaking, the individuals of both species are distributed, in most examples, repulsively for the width covering one~several to a considerable number of units. And the number of individuals of both species caught by the same basket was also less than that in the case when they were distributed independently of each other. However, when the unit length was shortened to one hook-interval, the existence of rather aggregative pattern extending to several hook-intervals at the maximum was alluded to in 3 examples, although the repulsive pattern was still maintained somewhat clearly in 4 examples.

On the other hand, the marlins are ranked at a little higher food rank than the tuna and often caught by the same row of gears mingled with the latter, but there is no direct predatory relation between these two. Contrarily, it is a well known fact that the hooked tunas are occasionally damaged by sharks which are caught by the same row of gears mingled with the former, although it is doubtful if freely swimming tunas are attacked by sharks as the hooked ones. Accordingly, the existence of some relations between the localities of hooked tunas and sharks is highly expected and this is evidently a very serious and interesting matter not only for the ecological but also for commercial purposes. Nevertheless, the catch rates of both species are apart from each other so far that the relation diagrams are apt to be strongly affected by the distribution pattern of the subordinate species, hence only several examples are illustrated in Fig. 16 (between tunas and marlins) and Fig. 18 (between tunas and sharks). In these examples the catch rate of tuna is extremely low as well as those of sharks consequently some accidental errors are inevitably expected. The correlation diagrams between the tunas and marlins seem to show a possible repulsive pattern, but the definite conclusion cannot be given, as the catch rate is very low. Either, nothing is deducible from the correlation diagrams between the tunas and sharks, because accidental errors are highly expected.

The method of analyzing the distribution pattern adopted in this paper is summarized as follows: at first the formulae representing the chance distribution are constructed, next the influences of the gradient of the distribution, the difference of the catch rate according to the depth and the existence of buoy lines are theoretically corrected in the formulae and lastly the distribution pattern is deduced from the deviation of the observed values from the corresponding estimated ones. However, some factors of errors still remain intact and on the other hand other factors of errors may be introduced during the computation or included in the basic assumptions. Namely, there is no evidence supporting that individuals belonging to the same school may be caught within a limited time, because the distribution of individuals at each part along the row of gears is represented as the pattern integrated during the period from the beginning of the setting to the end of the hauling of respective parts. On the other hand, this method is based on the assumption that the long-line fishes only individuals of a certain single species and that each baited hook shows the same probability of catching fishes or the probability shows gradient or differs according to the depth. But, practically, some factors of errors infringing the assumptions can be expected and these tend to make the distribution of fishes less contagious. Moreover, the effect of the occupation of hooks by individuals unifies the distribution even when the individuals belong to the same species and thus this must be taken into consideration when the whole or some parts of row are occupied very densely. Besides the above-mentioned factors of errors, another factor is influential on the observed values in Series I ——*i. e.*, series of the catches in each of 5 consecutive baskets may differ slightly according to the situation of the initial basket of counting the units. Consideration was given to each of these factors.

Besides the above-mentioned errors chiefly included in the observed values, some computation errors chiefly attributable to the uncertainty of constants computed from the actually observed distribution may be contained in the theoretically estimated values, especially those in which the influence of the gradient of the catch is taken into consideration. Special consideration was given to this.

Moreover, as mentioned already in the section of notes for decoding, X(k) simply represents the theoretical number of the occurrence of the couples of individuals spaced by k section-intervals (or hook-intervals), but is quite regardless as to whether some of the intermediate hooks are occupied by fishes or not. Accordingly, the distribution pattern cannot be analyzed purely theoretically, but it is indispensable to refer to the original records. To fill up this deficiency, another new device was proposed, in which the occupation of some of the intermediate hooks by fishes was taken into consideration. But still another factor remains and it brings the interpretation of the distribution pattern into a confusion, —— that is the order of the arrangement of the intervals spaced respectively. Still another method is proposed to solve this problem, although it is very doubtful whether accurate results are obtainable from the two series of analyses in this method or not, as it is very difficult to estimate the theoretical values, especially those in which the influence of the gradient is taken into consideration, computation errors are highly expected and moreover both the estimated and observed values in the last method are presumably very low.

Then, some consideration was given to the factors influential on the gradient and the difference of the catch rate according to the depth, but without any distinct results.

At the end of the article, several examples obtained by the different fishing methods were presented as appendices in which the distribution pattern in space or time was analyzed by the same method proposed in the proper part of this paper.

References

1) ARCHIBALD, E. E. A., 1948 : Plant populations. I. A new application of NEYMAN'S contagious distribution. *Ann. Bot. N. S.*, **12**, 221—235.

2) ASHBY, E., 1935 : The quantitative analysis of vegetation. *Ann. Bot.*, **49**, 779—802.

3) BARNES, H. & T. B. BAGENAL, 1951 : A statistical study of variability in catch obtained by short repeated trawls taken over an inshore ground. *Jour. Mar. Biol. Assoc.*, **29**, 649—660.

4) BARNES, H. & S. M. MARSHALL, 1951 : On the variability of replicate plankton samples and some application of contagious series to the statistical distribution of catches over restricted period. *ibid.* **30**, 233—263.

5) BEALL, G., 1935 : Study of arthropod populations by the method of sweeping. *Ecol.*, **16**, 216—225.

6) ————, 1939 : Method of estimating the population of insects in a field. *Biometrika*, **30**, 422—439.

7) ————, 1940 : The fit and significance of contagious distribution when applied to observations on larval insects. *Ecol.*, **21**, 460—474.

8) BEALL, G., 1942 : The transformation of data from entomological field experiments so that the analysis of variance becomes applicable. *Biometrika*, **32**, 243—262.
9) Blackman, G. E., 1935 : A study by statistical method of the distribution of species in grassland associations. *Ann. Bot.*, **49**, 749—777.
10) BLISS, C. I., 1941 : Statistical problems in estimating populations of Japanese beetle larva. *Jour. Econ. Ent.*, **34**, 221—232.
11) BOWEN, M. F., 1947 : Population distribution of beet leafhopper in relation to experimental field plot lay-out. *Jour. Agr. Res.*, **75**, 259—278.
12) CLAPHAM, A. R., 1938 : Over-dispersion in grassland communities and the use of statistical methods in plant ecology. *Jour. Ecol.*, **24**, 232—251.
13) COLE, L. C., 1946 : A theory for analysing contagiously distributed populations. *Ecol.*, **27**, 329—341.
14) COTTAM, G. & J. T. CURTIS, 1949 : A method for making rapid surveys of woodlands by means of randomly selected trees. *ibid.*, **30**, 101—104.
15) COTTAM, G., J. T. CURTIS & W. HALE, 1953 : Some sampling characteristics of a population of randomly dispersed individuals. *ibid.*, **34**, 741—757.
16) COTTAM, G. & J. T. CURTIS, 1955 : Correlation for various exclusion angles in the random pairs method. *ibid.*, **36**, 767.
17) ———————, 1956 : The use of distance measures in phytosociological sampling. *ibid.*, **37**, 451—460.
18) GOODALL, D. W., 1952 : Quantitative aspects of plant distribution. *Biol. Rev.*, **27**, 194—245.
19) KESTEVEN G. L. & T. W. BURDON, 1952 : Fishery Survey Report, No. 1. An introduction to the fisheries survey of the colony of Singapore, with a consideration of the methodology employed. Fish. Bull., No. 2, Fish. Dept., Singapore.
20) KITAGAWA, T. & T. YAMAMOTO, 1950 : Sampling survey of fisheries catch in Fukuoka Prefecture. Statistics and Research Division, Min. Agric. Forest., Jap. Gov. (in Japanese).
21) KONO, T., *et al.*, 1952 : Pattern of spatial distribution of the rice-stem borer, *Chilo simplex*, in a paddy field. *Res, Pop. Ecol.*, **1**, 65—82 (in Japanese with English summary).
22) KUROKI, T., 1956 : Theoretical estimation of albacore-shoals dimensions in accordance with the characteristics of fishing rates. *Mem. Fac. Fish. Kagoshima Univ.*, **5**, 78—90.
23) MAÉDA, H., 1953 : Ecological analyses of pelagic shoals I. Analysis of salmon gill-net association in the Aleutians. (2) Distribution of fishes on the gill-net. *Bull. Jap. Soc. Sci. Fish.*, **19**, 305—318.
24) ————, 1955 : Shoaling tendency in tuna observed in the Great Sunda Archipelago. IPFC/C55/Tech. 12.
25) MAKO, H., 1955 : A consideration on the density index of fish population. *Bull. Jap. Soc. Sci. Fish.*, **21**, 67—72 (in Japanese with English summary).
26) MARSHALL, J., 1936 : The distribution and sampling of insect populations in the field with special reference to the American bollworm, *Heliothis obsolata*. *Ann. Appl. Biol.*, **23**, 133—152.
27) MOOD, A. N., 1950 : Introduction to the theory of statistics. McGraw-Hill Book Co., 433 pp.
28) MORISITA, M., 1950 : Migration and population density of a water-strider, *Girris lacustris* L. *Contr. Ecol. & Physiol., Kyoto Univ.*, **65**, 1—149 (in Japanese with English summary).
29) ————————, 1952 : Experimental studies on the population density of an ant-lion *Glenuroides japonicus* M. L. *Physiol. & Ecol. (Kyoto)*, **5**, 1—16 (in Japanese with English summary).
30) ————————, 1954 a : Estimation of population density by spacing method. *Mem. Fac. Sci., Kyushu Univ., Ser. E.*, **1**, 187—197.

31) MORISITA, M., 1954 b : Experimental studies on the population density of an ant-lion *Glenuroides japonicus* M'. L. II. *Jap. Jour. Ecol.*, **4**, 71—79 (in Japanese with English summary).
32) ————————, 1957 : A new method for the estimation of density by the spacing method applicable to non-randomly distributed population. *Physiol. & Ecol.* (*Kyoto*), **7**, 134—144 (in Japanese with English summary).
33) ————————, 1959 : Measuring the dispersion of individuals and analysis of the distribution pattern. *Mem. Fac. Sci., Kyushu Univ., Ser. E*, **2**, 215—235.
34) ————————, 1951—59 : Personal communications.
35) MURPHY, G.I. & R.S. SHOMURA, 1953 : Long-line fishing for deep swimming tunas in the central Pacific July 1950—Sept. 1951. *Special Scientific Report No.* 98. *U.S. Dept. Interior, Fish and Wildlife Sev.*
36) MURPHY, G. I. & K. C. ELLIOT, 1954 : Variability of long-line catches of yellowfin tuna. *ibid.*, No. 119.
37) NAKAMURA, H., 1949 : The tunas and their fisheries. Takeuchi Shobo, Tokyo (translated by W. Van Campen, *ibid.*, No. 82, 1952).
38) NEYMAN, J., 1939 : On a new class of "contagious" distributions applicable in entomology and bacteriology. *Ann. Math. Stat.*, **10**, 35—57.
39) RICHARDS, O.W., 1936 : Some quantitative methods for analysis of insect associations. *Proc. Linn. Soc. London.* **146**, 33—36.
40) ————————, 1940 : The biology of the small white butterfly *Pieris rapae* with special reference to the factors controlling its abundance. *Jour. Anim. Ecol.*, **9**, 243—288.
41) ROMELL, G.I., 1930 : Comments on RAUNKIAER'S and similar methods of vegetation analysis and the "law of frequency." *Ecol.*, **11**, 589—596.
42) SILLIMAN R.P., 1946 : A study of variability on plankton townet catches of Pacific pilchard *Sardinops caerulea* eggs. *Jour. Mar. Res.*, **6**, 74—83.
43) TAGUCHI, K., 1959 : Studies on the estimate of the distribution density of salmon population of the high seas. *Bull. Jap. Soc. Sci. Fish.*, **25**, 335—341 (in Japanese with English summary)
44) TORII, T., 1952 : Stochastic method of analysis of insect populations. A treatise on ecology by N. YAGI and K. NOMURA, 216, 218, 237, 241, 244, 245, 255.
45) ————————, 1956 : The statistic approach in field population ecology. Jap. Soc. Promotion of Sci., Tokyo, 277 pp.
46) UMESAO, T., 1950 a : A quantitative representation of the social relation I. *Biol. Sci.*, **2**, 179—185 (in Japanese).
47) ————————, 1950 b : ———————— II. *ibid.*, **3**, 33—41 (in Japanese).
48) UTIDA, S., 1941—43 : Studies on experimental population of the azuki been weevil, *Callosobruchus chinensis*. I—VIII. *Mem. Coll. Agric., Kyoto Univ.*
49) UTIDA, S., *et al.*, 1952 : Pattern of spatial distribution of the common cabbage butterfly *Pieris rapae* in a cabbage farm. *Res. Pop. Ecol.*, **1**. 49—64 (in Japanese with English summary).
50) WINSOR, C. P. & G. L. CLARKE, 1940 : A statistical study of variation in the catch of plankton nets. *Jour. Mar. Res.*, **3**, 1—34.
51) YAMAMOTO, T., 1956 : On the characteristics of unit catch. Statistics and Survey Division, Min. Agric. Forest., Jap. Gov., 115 pp (in Japanese with English summary).
52) YOSHIDA, T. *et al.*, 1952 : On the distribution pattern of the spotted lady beetle *Epilachna sparsa orientalis*. *Res. Pop. Ecol.*, **1**, 83—93 (in Japanese with English summary).
53) YOSHIHARA, T., 1951—54 : Distribution of fishes caught by the long-line. I. Horizontal distribution, *Bull. Jap. Soc. Sci. Fish.* **16**, 367—369. II. Vertical distribution,

ibid., **16**, 370—374, Ⅲ. Swimming depth, *ibid.*, **18**, 187—190, Ⅳ. On the relation between κ and φ_0 with a table and diagram. *ibid.*, **18**, 1012—1014 (in Japanese with English summary).

54) YOSHIHARA, T., 1952 : On the type of frequency curve of the catch. *ibid.*, **18**, 241—244 (in Japanese with English summary).

55) ————, 1953 : On the distribution of *Tectarius granularis*. *Res. Pop. Ecol.*, **2**, 112—122 (in Japanese with English summary).

56) ————, 1954 : On the distribution of catches by tuna long-line. *Jour. Tokyo Univ. Fish.*, **41**, 1—26.

57) ————, 1957 : On the mechanism of capture by the long-line. FAO/57/4/2314.

鯨と採油量の一考察

1958～1959年の南氷洋における第2極洋丸船団の捕獲頭数と採油量について※

片　岡　昭　吉

Some Consideration on the Factors Affecting on the Antarctic Whale Oil Production in 1958～59 by the Kyokuyō-maru No. 2.

By

Akiyoshi KATAOKA

The whale mother ship kyokuyō-maru No. 2 participated in the Antarctic whaling during the period of 1958～59 and got a good catch amounting to 928.03 BWU (Blue whale Unit). However, the whale oil yield per BWU was unexpectedly poorer than those of other fleets operating in its adjacent waters. The author, superviser of this fleet, examined its reason on the basis of data obtained by his fleet and the results obtained are summarized as follows:

1. The blubber of whale containing much oil is the most important material for oil production.

2. As the blubber of whale caught by his fleet was thinner than those in others, the yield of oil was unexpectedly less than those of others.

3. The operation was done mainly during the early part of fishing period and in the easterly fishing ground, and his fleet caught slender whales.

4. Time expended from catch to flensing was longer than those in other fleets.

5. No distinct relation is observed between body length and yield of oil, but there is a remarkable correlation between yield of oil and volume or thickness of the blubber.

6. There was no significant difference in body length of caught whale between the catch of his fleet and those of others.

7. The proportion of oil lost in oiling process did not exceed 3.7 %, and therefore it seems that the amount of lost oil could not cause the poorness of oil yield of his fleet.

※ 水産講習所研究業績　第300号，1960年2月23日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 300.
Received Feb. 23, 1960.

緒　　言

戦後再開された南氷洋捕鯨業も，1958～59年の出漁で13回を数えるに至り，我が国水産業界におけるその地位も益々重大となってきた。第2極洋丸船団は1956年パナマ国籍のオリンピック・チャレンヂャー船団を極洋捕鯨株式会社が購入，同年より出漁したもので，今回で第3回目の出漁であったにもかかわらず，日本6船団中でも優秀な捕獲成績を挙げることができたが，製品の生産数量，特に，鯨油の生産（しろながす鯨換算1頭当りの生産数量．以下BWUと記す）は日本6船団中最低であった。

南氷洋捕鯨事業は国際捕鯨条約にもある通り，資源の保護とあわせて鯨体の完全利用を目標としているのであるから，捕獲頭数と採油量の関係は捕獲された鯨が大きいか小さいか，また捕獲適期に捕獲したか否か，更に捕獲した鯨が好条件で処理されたか否か等，種々の重要な問題を含んでいる。

今回同船団に乗船したので南氷洋捕鯨の漁期漁場等検討の参考とするため，同船団の鯨油生産量について種々考察を加えてみた結果，2，3の知見を得たので報告する。

なお，本報告の発表に当っては水産庁当局の了解を得た。使用した統計的数字は1959年3月23日の水産庁発表によった。

Table 1. Comparisons of catches and productions of whale oil respective fleets.

		Kyokuyō No.2	Tonan	Tonan No. 2	Nisshin	Nisshin No. 2	Kinjō
Catch whale (individual)	B	75 (1)	56	55	100 (1)	119 (1)	12
	F	1508 (4)	1255	1297 (2)	1542 (2)	1242	1021 (2)
	H	248	170	215	177	287	167
	S	59	205 (1)	282	235 (3)	217	96 (1)
	BWU	938.03 (3.0)	785.66 (0.16)	836.5 (1)	980.96 (2.5)	890.96 (1)	605.46 (1.16)
Whale oil (ton)		16270	13872	15585	19020	17507	11295
Oil per BWU (ton)		17.4	17.7	18.7	19.5	19.7	18.7

(　) …… lost whale, which are included into the number in respective columns.
Abbreviation B……Blue whale　F……Fin whale　H……Humpback whale
S……Sei whale

考　　察

(1) 脂皮の厚さと採油量について

鯨は同じ体長に対しても個体により肥瘦があり，従ってその油の生産量に著しい変化がおこることは既に知られている通りで，この鯨の肥瘦を表わす指標として脂皮の厚さが使用されている。

脂皮の厚さは鯨の種類・漁期等によって変化が著しく，南氷洋においてもこの例にもれず変化が著しいことは既に報告されている。

今次主として東経漁場で操業した3船団の各鯨種別の脂皮の厚さとBWU 1頭当りの採油量を示すと第2表の通りになり，おおむね第2極洋丸船団は他の2船団に比較して各鯨種とも脂皮が薄い。(測定部位は何れも体測背びれの下の1点で各船団とも共通である。)

Table 2. Relations between thickness of blubber and productions of whale oil per BWU by main fishing grounds.

Number of fishing grounds		3	4	5
		Kyokuyō No. 2	Tonan	Kinjō
Thickness of blubber (cm)	B	10.8	11.0	11.0
	F	7.3	7.5	8.5
	H	11.6	11.9	12.8
	S	6.3	6.5	6.6
Whale oil (ton)		17.4	17.7	18.7

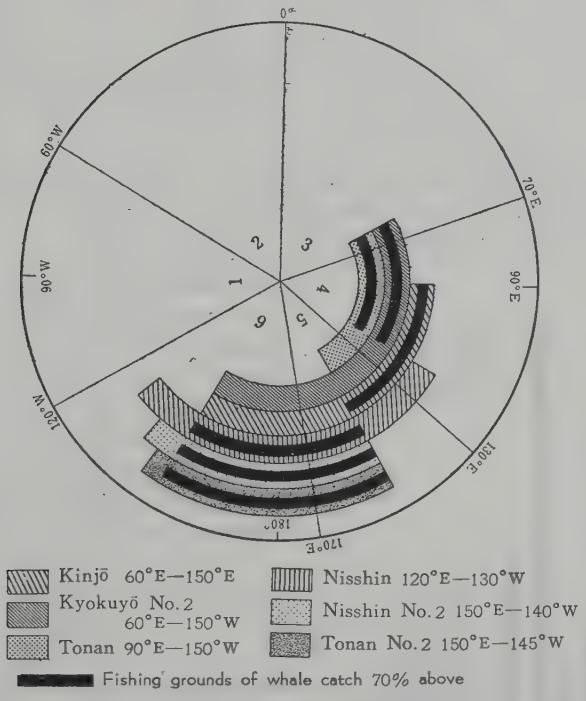


Fig. 1. Fishing grounds of Japanese 6 fleets engaged in the Antarctic Sea whaling.

これは本船団が痩せた鯨を多く捕獲したことになるが，これは次項において述べる漁期と関係があり，他船団に比し初漁期に捕獲が多く，中期以降に捕獲が漸減したためであって，ひいては鯨油生産量の少なかった一原因になったものと思われる。

このほかに鯨体の肥瘦については一般に，西経漁場の鯨の方が東経漁場の鯨よりも肥満していると漁業者の間では信じられている。

（2）体長と採油量について

採油量は捕獲した鯨体の大きさにも関係があり，普通一般には，大型の鯨体からは小型の鯨体より大量の

採油が出来るものである。然しながら，南氷洋において捕獲される鯨は国際捕鯨条約による資源保護上の体長制限があるので，同一種の鯨ではそれ程体長に著しい差異はない。今次1958～59年の各船団の捕獲した鯨について鯨種別平均体長と採油量を示すと第3表の通りである。何れも体長に著しい差異はなく，このう

Table 3. Average body length (in feet) of each species and whales caught by respective fleets.

	B	F	H	S	Oil per BWU (ton)
Kyokuyō No. 2	77.1	65.9	39.5	51.0	17.4
Tonan	77.0	65.9	38.9	51.1	17.7
Tonan No. 2	77.6	64.3	40.5	50.7	18.7
Nisshin	77.3	65.6	39.9	50.6	19.5
Nisshin No. 2	78.0	65.6	40.8	50.8	19.7
Kinjō	77.3	66.8	39.6	50.8	18.7

ちで各船団共最も捕獲の多かった，ながす鯨について平均体長とBWUあたりの採油量の相関を調べてみると相関係数は−0.17となり，F検定の結果0.05の有意水準では有意とはみなせない。他の鯨種についても同様のことがいえるものと思われる。

この結果から南氷洋における捕獲鯨とその採油量の関係は，鯨体の肥瘦に大きく影響されるが，体長にはその関係が認められない。このことは大倉ほか[7]も指摘しており，Alf. KLEM[8]の研究結果からみても明らかで，肥満した鯨は体長のほぼ同様な瘦せた鯨の優に2倍近い油を含んでいる。

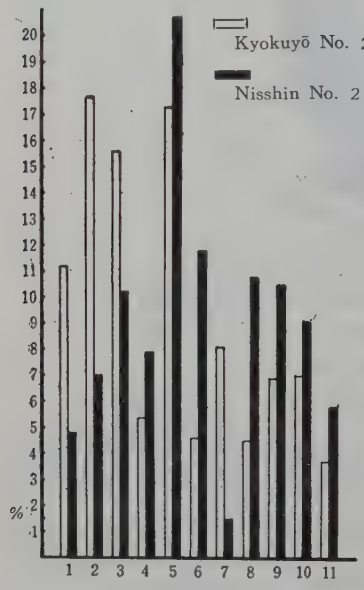


Fig. 2. Ratio of catch by each week.

(3) 捕獲時期と採油量の関係について

南氷洋捕鯨の漁期はおおむね1月から3月までで，この時期が南氷洋の夏季に当る。この夏季の訪れと共に氷が溶けて，ここに餌料となるEuphausiaが急にしかも豊富に発生するので，鯨はこれを求めて索餌廻游するものとされておる。従って初漁期の鯨は瘦せているが漁期の進むにつれ次第に栄養状態も良好となり，含油量も増加し，捕獲鯨からの採油量も増加する。この傾向から，捕獲は出来るだけ漁期の終り近くに多くすることが望ましく，国際捕鯨協定において捕獲開始の時期が以前よりも次第に遅れてきたのもこのためである。

このことについては大倉ほか[7]も，2月上旬以降脂皮の含油量が著しく増加することを指摘発表している。1958～59年における操業船団中BWU当りの採油量の最も多かった第2日新丸船団と本船団の各週別の捕獲割合を示すと第2図の通りであり，本船団は第2日新丸船団の実績に比し，初漁期の捕獲が非常に多く，中期以降の捕獲が低下している。これも本船団が他船団に比し鯨油の生産量が少なかった原因として見逃せないものである。

なお，本船団の各週別の鯨油の歩留りは第3図の通りで，これを月別にみると，1月は16.0噸，2月

18.2噸，3月20.2噸である。

Table 4. Comparison of whale caught, thickness of blubber and average body length in the fishing season of 1957/58 and of 1958/59.

	Fishing season	Catch whale (individual)	Thickness of blubber (cm)	Average body length (feet)
B	1957/58	120	11.6	77.1
	1958/59	75	10.8	77.1
F	1957/58	1322	7.5	64.6
	1958/59	1508	7.3	65.9
H	1957/58	23	11.9	41.0
	1958/59	248	11.6	39.5
S	1957/58	208	6.3	50.9
	1958/59	59	6.3	51.0

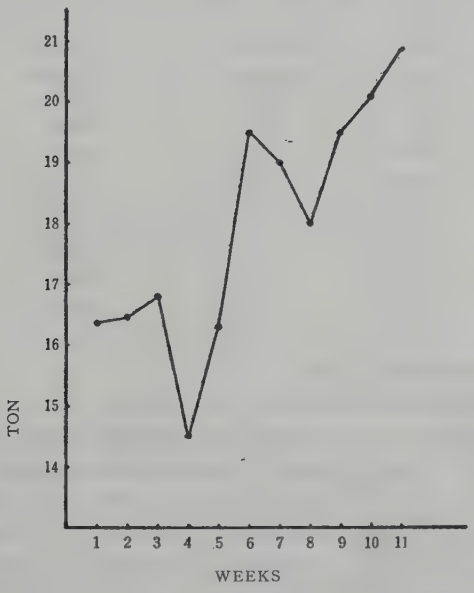


Fig. 3. Yield of each week.

（4）外国船団の採油量と本船団との比較

日本船団の捕獲した鯨のBWU 1頭当りの採油量は外国船団のそれに比べて著しく低い。これは鯨の脂皮の厚さや，鯨体の大きさにも若干の差違はあるが，処理方法が異なっていることにも起因するもので，日本船団は赤肉，うね及び皮の一部を冷凍や塩蔵するが，外国船団はすべて採油原料にする結果である。従って本船団が採油以外に処理したこれ等の部分から，同様に採油すると仮定すれば，次の通りの採油量の上昇を

見込むことが出来る。

	生産量（噸）	採油率	換算採油量（噸）
赤肉類	16973.5	5～7 %	848.7～1188.1
畝	1454.7	30 %	436.4
皮	160.6	70 %	112.4
計			1397.5～1736.9
BWU 1頭当り採油量			1.5～1.9

備考　1．採油率は本母船における従来の実験データによる。
　　2．うねすは½をうねとした。
　　3．赤肉類は赤肉・すのこその他を含む。

したがって本船団が，これらすべての原料から採油したとすれば，BWU 1頭当り 18.9～19.3 噸となり，本船団購入以前の実績と比較して，大差はないようである。

以下本船団がパナマ国籍で 1950～1951 年以降オリンピック・チャレンヂャー船団として従漁した当時の捕獲頭数・鯨油生産量及びBWU 1頭当りの生産量は第5表の通りである。

Table 5. Comparison of total catches, whale oil and average production of oil per BWU of this fleet during the period of under Panamanian and of Japanese.

Fleets	Fishing season	Catch (BWU)	Whale oil (ton)	Average prodcution of oil per BWU (ton)
Olympic Charenger	1950/51	999.6	20517	20.52
	1951/52	899.0	15991	17.78
	1952/53	1277.2	26342	20.62
	1953/54	1345.5	24767	18.40
	1955/56	1242.7	24820	19.97
Kyokuyō No. 2.	1956/57	669.9	11887	18.6
	1957/58	824.86	14650	17.8
	1958/59	938.03	16270	17.4

（5）製油工程における未回収鯨油について

本年度操業中の製油工程における未回収鯨油は第2図の通りである。

これを本船団がパナマ国籍のオリンピック・チャレンヂャー船団時代の実績と比較すると次の通りであり，オリンピック・チャレンヂャー船団当時の実績よりも遙かに未回収鯨油の量は少くなっている。

	オリンピック・チャレンヂャー		第2極洋丸
	1952～53	1954～55	1958～59
捕獲頭数（BWU）	1277.2	1345.2	938.03
鯨油生産高（噸）	26,342	24,767	16,270
BWU 1頭当り鯨油生産高（噸）	20.6	18.4	17.4
総油量を100 %とした場合の比率			
一次採油率（%）	78.7	74.8	789.5
回収採油率（%）	11.75	16.22	6.8
未回収油	9.55	8.91	3.7

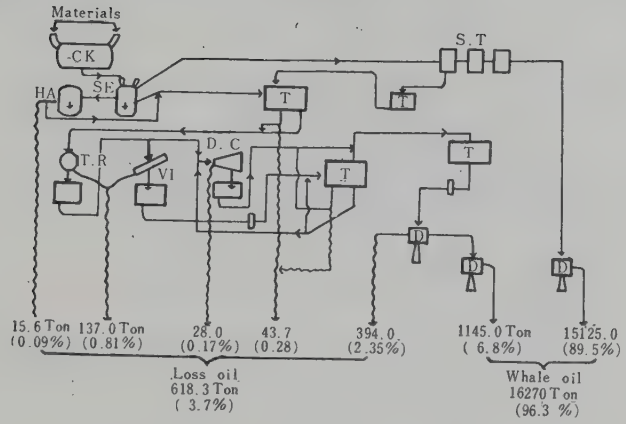


Fig. 4. The representation of processes of oil extraction and ratio of loss oil at each part.

Abbreviation

C K ……Cooker	H A ……Hatoman receiver	S E ……Separator
T R ……Trommel	V I ……Vibration	D C ……Decanter
S T ……Settling tank	T ……Tank D ……Delaval	Materials……Bluber and bone

未回収油の内訳

Tro, Vib, DC, Sludge	3.25 %	3.596 %	0.98 %
Har, Receiver, GR より Over board の分	0.9	0.184	0.37
GVK廃液	5.4	5.13	2.35

要　　約

採油量に関係のある脂皮の厚さ，体長，漁期，処理工程中における未回収油の量等について考察したが，その結果を要約すると，本船団の BWU 1 頭当りの鯨油生産量の少なかった原因と思われるものが 2, 3 あり，その他については他の船団との相違は余り認められなかった。

（1）採油の主原料が脂皮である関係上，脂皮の厚さ（脂皮の含油量）も採油量に大きな影響をあたえている。本船団の捕獲した鯨の脂皮が薄かったことは採油量の少なかった一原因であろう。

（2）上述の脂皮の厚さが薄かったということは，痩せた鯨の捕獲が多かったということであり，これは漁期に深い関係がある。一般に南氷洋では漁期の進むにつれて次第に鯨も肥満してくるものである。本船団は初漁期の捕獲が多く，中期以降の肥満した鯨の捕獲が少なかったのでこの結果になったものと思われる。

（3）BWU 1 頭当りの採油量と体長の関係は各船団の捕獲した鯨に体長の著しい差違は認められず，相関関係も認められなかった。

（4）採油量に深い関係のある処理工程中の未回収油については，他船団の報告が不明であったため比較は出来なかったが，本船団がパナマ国籍でオリンピック・チャレンジャー船団として出漁していた時代の記録と比較した結果，未回収油はチャレンジャー船団当時より約 50 %以上の減少を認めた。

終りに臨み，乗船中種々御指導を賜わった水産庁尾崎勝成氏，及び本稿を草する当り御指導御校閲を賜わった本所酒井森三郎，鶴田三郎の各先生に対し深甚の謝意を表する。

引　用　文　献

1）前田敬治郎：1952．捕鯨．いさな書房．
2）日本捕鯨協会：1955．南氷洋鯨族の生物学的調査報告，1954～55年．
3）――――：1956．――――，1955～56年．
4）――――：1957．――――，1956～57年．
5）――――：1958．――――，1957～58年．
6）――――：国際捕鯨統計，37～40巻．
7）大倉　俊一：1957．鯨油の品質の研究，25報・27報．日本水産株式会社研究所報告，第8号．
8）大村　秀雄：1942．鯨，その科学と捕鯨の実際，水産社．

"イタニグサ" *Ahnfeltia plicata* より寒天の新製造法に関する研究—Ⅱ.

心太の脱色及び脱水について※

小島良夫・田川昭治・香野　実

Studies on the New Method of Preparation of Agar-agar from *Ahnfeltia plicata*—Ⅱ. On the Decolorization and Dehydration of Crude Agar Gel※

By

Yoshio KOJIMA, Shōji TAGAWA and Minoru KŌNO

In the previous paper[1], the authors had reported that the agar-agar had been extracted in good yield by treating *Ahnfeltia plicata* with dilute NaOH solution at 120°C for 3 hours after fore-treating it with dilute NaOH solution. In this method, the most difficult process is the decolorization of dark brownish crude agar gel extracted from *Ahnfeltia plicata* with dilute NaOH solution. In this report, the authors attempted to decolorize and dehydrate the crude agar gel.

The results obtained were summarized as follows.

1) It was effective to soak the stripped crude agar gel in running water for the purpose of decoloring and dealkalizing.
2) When the freezing method was used in dehydration of crude agar gel, it was effective to bleach the dehydrated agar gel with 0.3 % NaOCl solution. (Table 1.) The other side, in the use of press method, it was more effective to bleach the crude agar gel with dilute NaOCl solution (available Cl, 0.04 %) after having removed alkali by running water (Table 2).
3) On the dehydration of crude agar gel by press method, the last pressure values of 1st stage and 2nd stage were 64 g/cm^2 and 4.1 kg/cm^2, respectively.
4) The yield of agar-agar prepared from *Ahnfeltia plicata* by the above mentioned process showed 16.4 % for the refined materials and jelly strength of it 650 g/cm^2.

※ 水産講習所研究業績　第301号, 1960年2月11日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 301.
Received Feb. 11, 1960.
1959年10月 日本水産学会秋季大会（於大阪）にて講演発表

緒　　言

著者等は前報[1]において，**イタニグサ** *A. plicata* を稀薄アルカリ溶液で 75°C，4時間処理して，寒天質を溶出させず，或る程度の色素を溶出させ，更に皮質を軟化させて，寒天質の抽出を容易にする前処理法を報告し，次にこの**処理イタニグサ**を稀薄アルカリ溶液で 120°C，3時間蒸煮して，従来の方法より優れた伊谷寒天の製造法を報告した。

しかしながら，本製造法における難点は，寒天質抽出の際，アルカリによって溶出され，心太中に混入する暗褐色の色素の除去である。著者等はこれについて諸種の実験を行い，併せて心太の脱水に圧搾法を試みて，略々満足すべき結果を得たので報告する。

実験及び考察

Ⅰ 試　　料

試料に供した原藻は，沿海州産**イタニグサ** *A. plicata* で，これを水洗して付着せる土砂を落とし，前報記載の方法[1]で前処理して，前処理原藻とした。これに 25 倍量の 0.5 %苛性ソーダ溶液を添加し，オートクレーブで 120°C，3時間蒸煮して寒天質を抽出した。ブフナー濾斗に濾布を敷いて残渣を分離し，濾液を一夜放置して凝固させ，心太とした。これを細状にして（以後細状心太という）実験に供した。

Ⅱ 清水交換による心太の脱色および脱アルカリ

抽出後の寒天液に，還元漂白剤（例えばハイドロサルファイト，ロンガリット，ブランキット）を直接添加して脱色を試みたが，硫化物と思われる沈殿を生じ，好結果が得られなかった。又，酸化漂白剤（例えば次亜塩素酸カルシウム，次亜塩素酸ソーダ，塩素水，過酸化水素水，過酸化ソーダ）を使用して脱色を試みたが，僅かながら不溶性沈殿を生じ，又，心太のゼリー強度が低下して，良好な結果が得られなかった。そこで，暗褐色の細状心太を流水中に浸漬して，脱色及び脱アルカリを試みた。最初は心太中の色素，アルカリと，清水との交換が速やかに進行したが，時間の経過とともに，交換が緩慢になり，18時間以後は，心太の色調の変化は殆んど見られず，稍乳褐色を呈するに及んだ。そこで，その使用水量を求めるために，1 ℓ の細状心太を 2 ℓ の清水に浸し，静かにかきまぜ，放置し，清水が着色したら新しい清水と交換した。このようにして，7回の交換を行い，全使用水量は 14 ℓ で，5時間を要した。脱色された心太は，清水交換したものと，略々同様の色調であった。すなわち，この方法が最も良好な脱色効果を示した。

Ⅲ 凍結法による伊谷寒天の製造

清水交換した稍乳褐色の細状心太を，−5°Cの凍結室で，12時間凍結した。撒水融解後，脱水し，乾燥したところ，褐色の寒天となった。これは，心太では色調が乳褐色で，色素の存在が僅かであっても，凍結すると心太の周囲から結氷し，色素は次第に心太の中心に濃縮されるために，脱水後の寒天に，その存在が顕著に現われたものと考えられる。そこで，この脱水寒天を，種々の漂白剤で処理して，脱色を試みた。結果は第1表に示す通りである。

表に見られる通り，次亜塩素酸カルシウム溶液で処理したものは，製品に不溶解物の生成が見られた。又，抽出後の寒天液を，稀塩酸で中和したものにも，同様の現象がみられた。脱水寒天を，0.3 % 次亜塩素酸ソーダ溶液で処理したものが，最も良好な結果を示した。

Table 1. Results upon the bleaching of dehydrated agar gel obtained from *Ahnfeltia plicata* by freezing method.

No.	Bleaching condition	Dechlorinizing condition	Agar-agar		Jelly	
			Color	Yield (%)	Strength (g/cm^2)	Remarks
1	0.1 % $Ca(OCl)_2$ 20 min.	——	Brown	14.5	750	Brownish
2	〃	0.35 % HCl 20 min.	Brownish	14.8	610	Insol. matter suspended
3	0.2 % $Ca(OCl)_2$ 20 min.	〃	Yellowish	14.5	470	〃
4	0.2 % $Ca(OCl)_2$ 20 min.	0.05 % $Na_2S_2O_4$ 20 min.	〃	14.2	630	〃
5	0.2 % NaOCl 30 min.	——	Yellow	16.8	730	
6*	0.2 % NaOCl 20 min.	——	Yellowish	15.0	530	Insol. matter suspended
7	0.3 % NaOCl 30 min.	——	〃	16.1	760	Good
8	0.45 % NaOCl 30 min.	——	Yellowish white	16.6	620	Good

＊Crude agar solution is neutralized with 3.6 % HCl to pH 6.2.

Ⅳ 圧搾脱水法による伊谷寒天の製造

Ⅳ—1 次亜塩素酸ソーダ溶液による心太の脱色，並びに圧搾脱水

テングサ及びアルカリ処理オゴノリからの心太の圧搾脱水については，既に種々の報告がなされている。[2)3)4)5)6)]

著者等は，伊谷寒天製造において，圧搾脱水法の採用を試みた。先ず，清水交換した細状心太を圧搾脱水して，フイルム状寒天ゲルを得たが，凍結脱水の場合と同様，褐色を呈した。そこで，更に脱色を試みた。このゲルは，凍結脱水の場合に較べて厚さが大きいので，凍結寒天ゲルに使用したのと同濃度の次亜塩素酸ソーダ溶液では，脱色が不充分であった。次に，その濃度を濃くして種々脱色を試みたが，製品のゼリー強度低下が著るしく，満足な結果が得られなかった。そこで，清水交換後の細状心太を，次亜塩素酸ソーダ溶液で脱色した後，圧搾脱水を行った。その結果は第２表に示す通りである。

Table 2. Bleaching of crude agar gel with NaOCl solution.

Jelly strength of crude agar gel (g/cm^2)	Concn. of NaOCl (available Cl, %)	Agar-agar		Jelly		
		Yield (%)	Color	Strength (g/cm^2)	Color	Odor
500	0.027	16.9	Yellowish brown	640	Yellowish brown	Cl odor
560	0.034	16.3	Yellow	680	Yellowish white	〃
565	0.041	16.0	Yellowish white	670	〃	〃
510	0.047	16.5	Yellowish white	640	〃	〃

Note : Time of bleaching, 1 hr.

次亜塩素酸ソーダ溶液の有効塩素が，0.04 %の場合，最良の結果が得られた。脱色後の心太は，乳白色を呈し，流水で1時間脱塩素後，圧搾脱水し，乾燥して，フイルム状伊谷寒天とした。この寒天のゼリー強度，色調は良好であったが，塩素臭が感知せられた。

Ⅳ－2　稀薄酢酸溶液による脱塩素

清水交換後，次亜塩素酸ソーダ溶液で脱色した心太を水洗し，種々の pH の酢酸溶液中に 20 分間浸漬して，脱塩素を行った後，水洗，圧搾脱水，乾燥して，フイルム状寒天とした。その結果は第3表に示す通りである。pH 5.0～5.5 の酢酸溶液で処理したものが，塩素臭もなく，最も良好な結果を与えた。

Table 3. Dechlorination of crude agar gel with dil. CH_3COOH.

pH value of CH_3COOH before dechlorination	pH value of CH_3COOH after dechlorination	Agar-agar		
		Yield (%)	Jelly strength (g/cm^2)	Cl odor
3.6	4.4	16.5	700	a little
4.4	5.0	16.8	650	〃
5.0	5.8	15.8	670	odorless
5.5	6.0	14.8	630	〃

Note : Time of dechlorination, 20min.

Ⅳ－3　心太の過酸化ソーダ溶液による脱色，並びに圧搾脱水

清水交換後の細状心太を，種々濃度の過酸化ソーダ溶液で脱色し，水洗後，圧搾脱水，乾燥して，フイルム状寒天とした。結果は第4表に示す通りである。

Table 4. Bleaching of crude agar gel with Na_2O_2 solution.

Jelly strength of crude agar gel (g/cm^2)	Concn. of Na_2O_2 soln. (%)	Agar-agar			
		Yield (%)	Jelly strength (g/cm^2)	Color	Odor
470	0.6	17.1	760	Yellow	Odorless
450	1.15	——	800	Yellowish white	〃
470	1.72	17.3	770	〃	〃

Note : Time of bleaching, 2 hrs.

表に示すように，過酸化ソーダの使用は，次亜塩素酸ソーダの場合に較べ，寒天ゼリーの色，臭，強度も非常に良好であった。しかし，漂白作用が緩慢で，脱色に2時間を要し，又，可成り高濃度の溶液を心要とするので，実用的には余り得策でないように思われる。

Ⅳ－4　脱色細状心太の圧搾脱水

処理イタニグサ 70 g より抽出した細状心太 1,400 g を，18時間清水交換し，次亜塩素酸ソーダ溶液（有効塩素 0.04 %）で脱色し，稀酢酸溶液（pH 5.5）で脱塩素した。これを1時間水洗し，水切り後，脱水枠内の濾布上に置いた。この場合，圧搾後，心太が濾布上からはみ出さないよう，適当量の心太を濾布の中央部に置き，その上に濾布を重ね，心太を濾布で挟んだ。このようにして，心太を3段積むごとに，圧力の均一化をはかるために，濾布と略々同じ大きさのジュラルミン製円板を濾布間に挟み，11～12段に心太を積み重ね，最上段に鉄製円板を置いた。

圧搾は2段階にわけて実施した。すなわち，第1段階は鉄製円板上に 10 分ごとに分銅をのせて荷重を増

し，80分後に61.4 g/cm² の圧力とした。次に第2段階の圧搾は，油圧機により10分ごとに圧力を増加し，第2段階の圧搾開始後40分で，4.1kg/cm² の圧力とした。脱水後の寒天ゲルは，濾布からはがし風乾後，65°Cに2時間乾燥してフイルム状伊谷寒天とした。第1段階の脱水率（脱水量×100/全含水量）は81.5％で，第2段階のそれは，93.4％であった。又，脱水後のゲル中の寒天濃度は13％であった。この脱水過程を示すと第1図のようである。

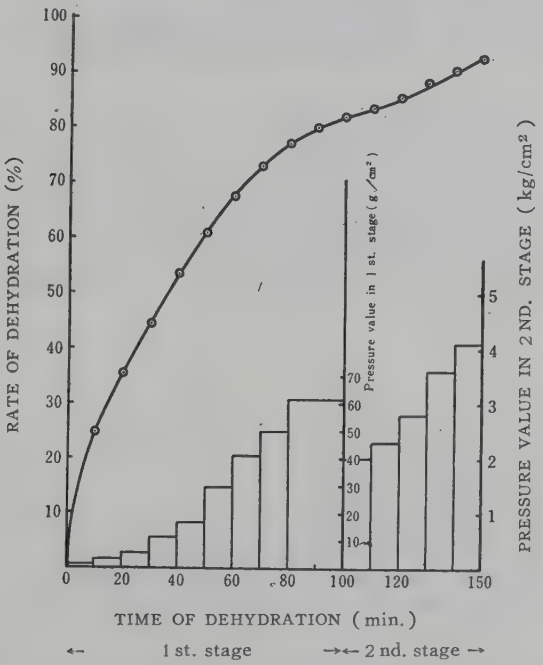


Fig. 1. Dehydration curve of the crude agar gel prepared from *A. plicata*. The curve showed the rate of dehydration and the histogram showed the pressure value in each stage.

又，この方法で製造したフイルム状伊谷寒天の製品結果（9例）は，第5表に示す通りである。

Table 5. Yield of agar-agar prepared from *A. plicata* by press method in laboratory scale (9 examples).

	Jelly strength of crude agar gel (g/cm²)	Residue to alkali treated material (%)	Yield (%)		Jelly strength of agar-agar (g/cm²)
			To the alkali treated material	To the refined material	
Min. and Max.	550～620	26.1～28.7	18.9～21.3	15.1～17.0	——
Mean	580	27.1	20.0	16.0	650

要　　約

1，前報記載の方法により，**イタニグサ** *A. plicata* を稀薄アルカリ溶液で前処理し，それより抽出した心太を細状となし，18時間流水洗して，心太の脱アルカリ，脱色を行った。

2，清水交換後の心太の脱水に，凍結法を用いる時は，脱水寒天ゲルを，0.3％次亜塩素酸ソーダ溶液で脱色し，水洗，乾燥して，良好な伊谷寒天が得られた。

一方，圧搾法を採用する時は，清水交換後の心太を，次亜塩素酸ソーダ溶液（有効塩素0.04％）で1時間脱色し，水洗後，pH 5.0～5.5の酢酸溶液で脱塩素し，水洗，圧搾脱水して，良好な伊谷寒天が得られた。

3，伊谷寒天製造に圧搾脱水法を採用した。圧搾過程として，第1段階は100分間で，最終圧64.1g/cm²，第2段階は50分間で，最終圧4.1kg/cm²で実施し，脱水率はそれぞれ，81.5％，93.4％であった。脱水後のゲル中の寒天濃度は13％で，これを乾燥してフイルム状伊谷寒天が得られた。

4，圧搾脱水法によって得た伊谷寒天は，稍々黄色を呈したが，収率は精原藻に対し，平均16.4％で，そのゼリー強度は平均650g/cm²を示し，良好な製品であった。

終りにのぞみ，本実験の試料の提供を受けた東海化成ＫＫに深謝し，実験に協力された都原靖人君に謝意を表する。

文　　献

1）小島良夫・福島保明・香野実：1959．本報告，**9**（1）．
2）今井　貞二：1920．日本特許，第35731号．
3）井手　正文：1950．日本特許，第185638号．
4）Okada, I., I. Osakabe, Y. Kuratomi and T. Kikuchi：1952. *J.T.U.F.*, **39**（1）.
5）舟木好右衛門・井上啓次郎・小島良夫：1953．日本特許公告，第3180号．
6）小島良夫・日下部重朗：1953．日本水産学会（於 津）にて講演発表．

"イタニグサ" *Ahnfeltia plicata* より寒天の新製造法に関する研究—Ⅲ.

伊谷寒天製造の工業化について※

小島良夫・田川昭治・香野　実

Studies on the New Method of Preparation of Agar-agar from *Ahnfeltia plicata*—Ⅲ. On the Industrialization for Manufacturing Itani Agar※

By

Yoshio KOJIMA, Shōji TAGAWA and Minoru KŌNO

Having succeeded in the preparation of agar-agar with good yield by the proposed method, the manufacture of Itani agar from *Ahnfeltia plicata* was carried out on the industrial scale.

Based on the results obtained in our laboratory, a flow sheet for the production was determined and the amount of materials for treating 100 kg of raw materials was calculated as shown on the Fig. 1. On the foundation of a flow sheet, the apparatus in main process as shown on the Figs. 3, 4 and 5. On the treating 9,100 kg of raw materials per month after four months, the yield and jelly strength of Itani agar were found to be 11.4 % for raw materials and 650 g/cm², respectively.

It is confirmed, therefore, that the production of the Itani agar on an industrial scale is nearly the same as on the laboratory scale.

著者等は既に**イタニグサ**の稀薄アルカリ溶液による前処理法，稀薄アルカリ溶液による寒天質の加圧抽出法，清水交換及び次亜塩素酸ソーダ溶液による心太のアルカリ及び色素の除去法ならびに心太の圧搾脱水法等を採用して従来の製造法に優る伊谷寒天の製造法を詳細に報告した[1)2)]。従来の石灰添加煮熱法では伊谷寒天の収率が精原藻に対して約 10 %，ゼリー強度が 350g/cm² に留まっていたが，本製造法によってゼリー強度 650～700g/cm² を示し，16～17 %の収率を挙げることが出来た。

この方法によって伊谷寒天を工業的に製造し得る充分な見通しを得たので基礎研究の結果より製造工程および物質収支を決定し，ついで諸設備を得て工業化試験を行ったのである。その結果，研究室にて得られた

※ 水産講習所研究業績　第302号，1960年２月11日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 302.
Received　Feb. 11, 1960.
1959年10月 日本水産学会秋季大会（大阪）にて講演発表

と略々近い成績を得ることが出来た。

I 工業化試験計画

すでに報告した詳細な基礎研究の結果より第1図に示すような原藻100 kg（精原藻80 kg）からの伊谷寒天製造工程ならびに所要物質収支を決定した。

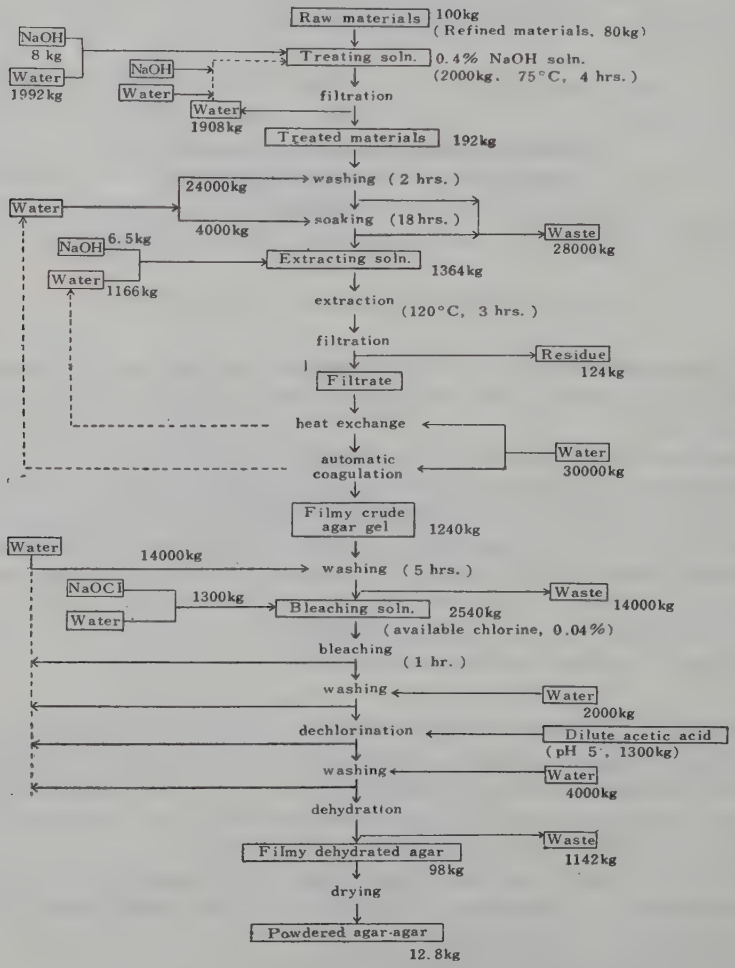


Fig. 1. Flow sheet of agar manufacture from *Ahnfeltia plicata*.

基礎研究では**イタニグサ**から伊谷寒天の収率は精原藻に対して 16 %を示したが工業的生産では粗原藻(以下単に原藻という)から出発するため草歩 80 %を考慮すると，収率は 12.8 %になる。又この製造法は他の寒天製造法（テングサ類，オゴノリ等）に比して原藻 100 kg に対して 61 トンの多量の工業用水を必要とした。

次にこの物質収支計算より月産 5,000 ポンド（2,250 kg）の伊谷寒天製造を目標とし，1 日原藻 700 kg (一工程 350 kg で 2 回操業) を処理するための諸装置を設計し，第 2 図に示すような設備と工程により工業化試験を行った。

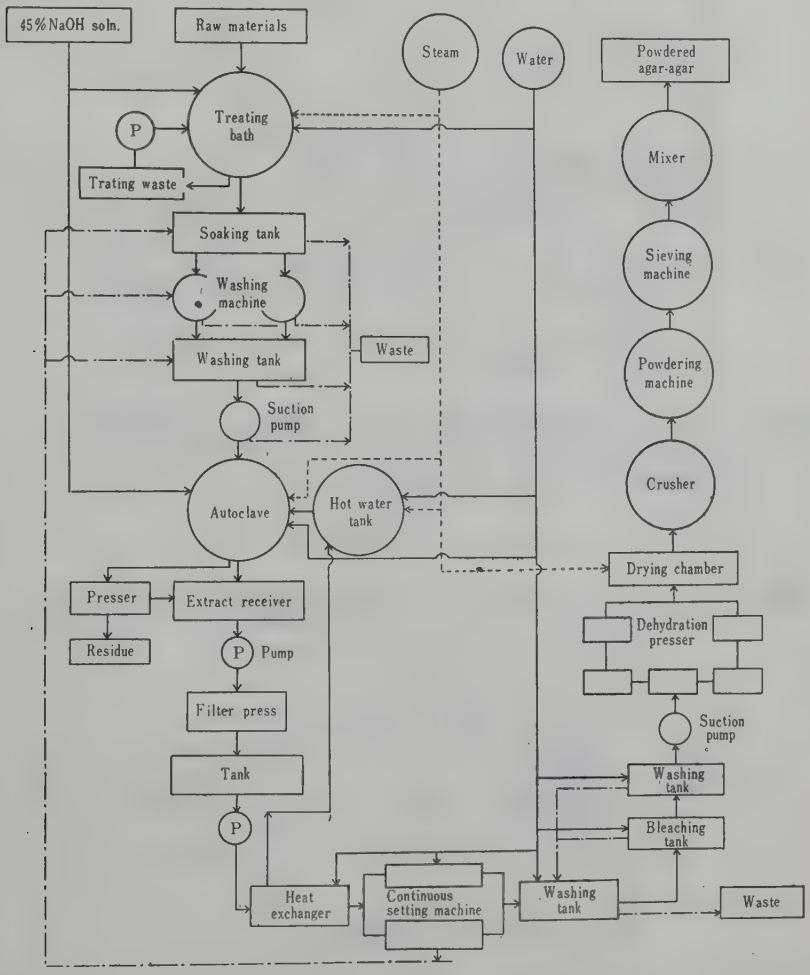


Fig. 2. An arrangement of pilot plant.

本製造工程中特に重要な原藻の前処理および寒天質の加圧抽出装置の断面図は第3図に示すようである。

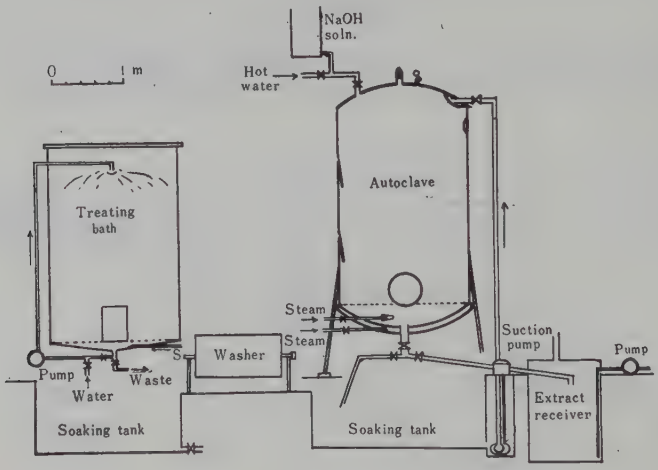


Fig. 3. Apparatuses for the alkali treatment of *Ahnfeltia plicata* and the extraction of agar-agar from it.

原藻処理槽の内容積は 7 m³ で処理温度の調節を目的として環流塔を附し，処理液を循環させるようにしてある。処理後の廃液は貯槽に流出させ，以後苛性ソーダの補充で数回反覆使用する。**処理イタニグサ**は取出口より流水中の浸漬槽に掻出して浸漬し，洗浄機で爽雑物およびアルカリを除去し，更に一夜水浸したる後吸引ポンプで抽出釜に送る。オートクレーブの内容積は 7.7 m³ で，温水，苛性ソーダ等を注加したる後加熱蒸気により最適条件の下で寒天質を抽出する。抽出完了後，95°C まで放冷し，濾過板を通して濾液は放出槽に注入される。

寒天液の熱交換による冷却，連続凝固ならびに心太の脱色装置の略図は第4図に示すようである。

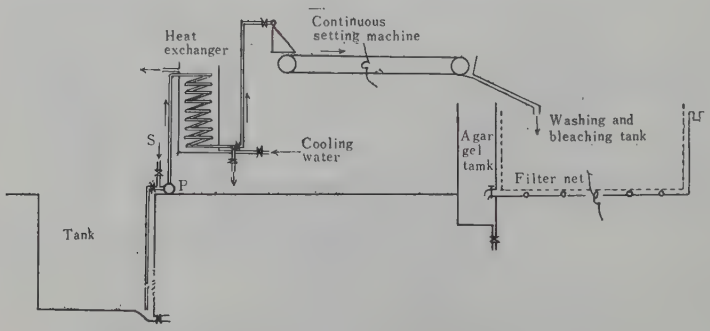


Fig. 4. Apparatuses for setting the agar soln. and decolorization of crude agar gel.

濾過後の黒褐色寒天液はギヤポンプにて熱交換器に送られ，液温 40°C 付近まで低下され，更に凝固機の傾斜板で 35～36°C まで低下される。

連続凝固機は錫引鉄板を無限ベルトとして変速機により速度を調節する。ベルトの下面を冷水噴射で冷却し，寒天液の凝固を速かにしている。凝固した膜状心太は凝固機の終端より水洗脱色槽に落下する。脱色槽は内部に周囲金網で張った濾過面を設けてある。先ず清水を流出しつつ心太中のアルカリおよび色素の清水交換を行う。膜状心太が略々無色透明となるのに約 12 時間を要する。次に稀薄次亜塩素ソーダ溶液で漂白，稀薄酢酸液で脱塩素したる後，水洗して心太貯槽に移し，吸引ポンプで脱水工程に送る。

心太の脱水装置は第 5 図に示すようである。

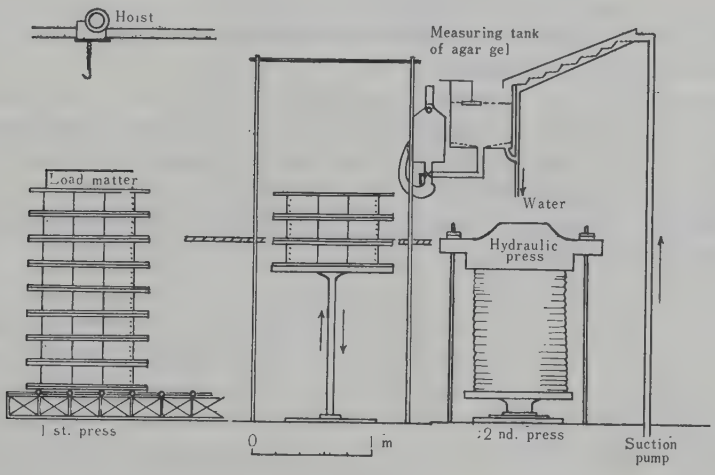


Fig. 5. Apparatus for dehydration of crude agar gel.

水と共に吸引ポンプで揚高された心太は傾斜濾面で送水と分離されて貯槽に入る。脱水枠中の脱水濾布へ心太計量器で一定量の心太が収容されて包まれ，順次積載される。下積みされた心太は積載中でも自重により絶えず脱水が進む。 8 コの脱水枠中に収容される心太は約 1,500 kg で約 110 枚のフイルム状寒天となる。積載後，上部脱水枠の内に荷重体（1 コ重量 250 kg）を置き第 1 次脱水を行う。脱水進行と共に荷重体の数を増し，積載高が低下するに従って上部から脱水枠を取除く。第 1 次脱水終了後は約 2 枠の高さとなる。第 1 次脱水終了後の心太は脱水枠を除去し，3 組合して第 2 次脱水工程に移す。第 2 次脱水は水圧機により除々に圧搾し，最終圧力は膜状心太 1 cm^2 に対して 5 kg である。全脱水時間は約 10 時間を要する。

脱水後，脱水濾布より剝離したフイルム状寒天は熱風乾燥により乾燥されて後，粉砕，調整されて粉末伊谷寒天となる。

Ⅱ　試験結果および考察

以上の製造工程および装置によって**イタニグサ**原藻を 1 日 350 kg 処理して伊谷寒天製造の工業化試験を行った。一工程の合計所要時間は約 75 時間であるが 1 日 10 時間操業としたため約 6 日を要した。

試験開始後 4 ヵ月目において原藻に対して平均 11.4 %の収率と，650～700 g/cm^2 のゼリー強度を示した

やや薄黄色の伊谷寒天を連続的に製造することが出来た。この収率は基礎研究で得た 12.8 % に比してやや劣った結果を示したが，これは

1．抽出後の残渣に付着あるいは含有している寒天を完全に回収していないこと。

2．この試験期間では新製造法に対する技術が習熟の点に到達していないこと。

などが起因している。今後これらの点の補足および向上によって順次所期の目的に達するものと考える。しかしながら既往の石灰煮熟法による収率約 8 %と比較すれば，一応本試験は成功したものと考える。

Ⅲ　要　　約

1．すでに発表した**イタニグサ**より寒天の新製造法の工業化試験を行った。

2．基礎研究で得られた結果より，まず原藻 100 kg に対する製造工程および物質収支を計算し，ついで一工程原藻 350 kg 処理の工業化試験設備を行った。

3．試験開始後 4 ヵ月において，1 日原藻 350 kg 処理で粉末伊谷寒天の平均収率 11.4 %，製品ゼリー強度 650～700 g/cm² の成績を得た。これは基礎研究の収率 12.8 %にやや劣ったが，今後操作の補足および技術の習熟によって所期の目的に達し得ると考える。しかし既往の石灰煮熟法によった収率約 8 %，製品ゼリー強度 350 g/cm² と比較すれば本法の工業化試験成績は一応成功したものと考えられた。

終りに臨み本研究および試験に当り，終始援助を与えられた東海化成株式会社（神奈川県平塚市）ならびに化研工業株式会社（長野県茅野市）に厚くお礼申上ぐる次第です。

文　　献

1）小島良夫・福島保明・香野　実：1960．イタニグサより寒天の新製造法に関する研究―Ⅰ．本報告，**9**（2）．

2）小島良夫・田川昭治・香野　実：1960．イタニグサより寒天の新製造法に関する研究―Ⅱ．本報告，**9**（3）．

海洋性硫酸塩還元細菌に対する食塩濃度の影響※

畑　　幸　彦

Response of Marine Sulfate-Reducing Bacteria to the Salinity of Culture Medium※

By

Yoshihiko HATA

In the previous paper, it has been shown that the distribution of sulfate-reducing bacteria in the bottom sediments in the estuary was influenced by the chlorinity of the bottom water; the population of sulfate reducers enumerated by sea water medium was abundant in marine and brackish environments but scanty in fresh water zone, and number of sulfate reducers counted by fresh water medium was abundant in fresh water and brackish regions but few in sea water zone.

The present paper is concerned with the response to the salinity of culture media, of the sulfate-reducing bacteria isolated by use of sea water medium from various marine and the estuarine mud or water samples.

The influences of NaCl concentration or salinity on the growth and the sulfate-reducing activity of these bacteria were examined by use of the basal medium having the composition as has been shown in Table 1. The results obtained are given in Tables 2—7 and Figs. 1—3, and may be summarized as follows:

1) Most of the strains of sulfate reducers isolated could grow within NaCl concentrations of 1.0—6.5 %, and few of them could develop on the media containing NaCl in lower as well as higher concentration than the above mentioned. (Tables 2—4)
2) The optimum NaCl concentration the growth and the sulfide production by these bacteria was about 2.0—3.0 %. (Tables 5—7 and Figs. 1—3)

These results suggest that these strains are typical marine organisms.

The tolerance and the adaptation of these bacteria to extreme salinity are shown in Figs. 4—12, and may be summarized as follows:

1) In the normal population of these cultures, a small number of cells could grow on

※ 水産講習所研究業績　第303号, 1960年2月11日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 303.
Received Feb. 11, 1960.

the media containing NaCl in lower or higher than the range which was shown in Table 2. (Figs. 4—6)

2) In the cultures which were preliminarily adapted to the media having extreme salinity, the proportions of the cells capable of growing beyond the above mentiond range of NaCl concentrations were somewhat increased. (Figs. 7—12)

These facts suggest that these bacteria could adapt, to some extent, to extremely low or high salinity.

The tolerance of these organisms to washing by the solutions of different osmotic pressure and suspending in these solutions are as shown in Fig. 13. These data show that when these bacteria were treated in short time with the extremely hypotonic or hypertonic solutions, a large number of the cells were injured but some of them survived.

既報[1]のように，河口水域の底土中における硫酸塩還元細菌の分布状態は，海水培地* を用いた場合には純淡水域にはきわめて少ないが汽水域および海水域にはほぼ一様に多数見出され，淡水培地** を用いた場合には海水域にははなはだ少ないが汽水域および純淡水域にはほぼ同程度に多数見出された。このことから，このような水域には海洋性および淡水性の2群の硫酸塩還元細菌が存在しており，それぞれの分布が環境の塩分濃度によって支配されていると考えた。

本報では，各地の主として沿岸海域および汽水域から海水培地を用いて分離された硫酸塩還元細菌の，発育に必要な食塩濃度の範囲，およびそれらの発育ならびに硫化物生成作用におよぼす食塩濃度の影響を明らかにし，さらにこれらの細菌の低食塩濃度または高食塩濃度に対する適応性あるいは抵抗性について検討した。

実　　験

(1) いろいろの水域から海水培地で分離された硫酸塩還元細菌の，発育に必要な塩分濃度

さきに[2]，舞鶴湾の底土から分離された硫酸塩還元細菌の1株について硫化物生成におよぼす塩分濃度の影響を明らかにしたが，今回はさらに舞鶴湾，広島湾，三田尻湾および下関地方沿岸における海水域および汽水域の底土または水から，海水培地を用いて分離された硫酸塩還元細菌の，発育に必要な食塩濃度の範囲を検討した。実験方法はつぎのとおりである。

海水調製の液体培地（本頁脚註の海水培地から Agar を除く）に 30°C で2日間前培養された硫酸塩還元細菌の純粋培養を，第1表の組成の基礎培地*** にいろいろの濃度の食塩を加えた被検培地に少量ずつ接種して 30°C で2週間培養し，黒色硫化物の生成および液の混濁によって発育の有無をみた。接種にあたっては前培養からの塩類の導入を避けるため，培養を 2,500 r.p.m. 10分で遠心集菌し，滅菌された 1.1 M ブ

---

* Ca-lactate 3.5 g, Beef extract 1.0 g, Peptone 2.0 g, L-Ascorbic acid 0.1 g, $MgSO_4 \cdot 7H_2O$ 0.2 g, K_2HPO_4 0.2g, $FeSO_4 \cdot 7H_2O$ 0.2g, Agar 3.0 g, Filtered sea water 1,000 ml, pH 7.5.

**Ca-lactate 3.5 g, Beef extract 1.0 g, Peptone 2.0 g, L-Ascorbic acid 0.1 g, Na_2SO_4 1.5 g, $MgSO_4 \cdot 7H_2O$ 2.0 g, K_2HPO_4 0.5 g, $FeSO_4 \cdot 7H_2O$ 0.2 g, Agar 3.0 g, Tap water 1,000 ml, pH 7.5.

***この組成は後報[3]のように，Na^+ および Cl^- 以外はこの種の細菌の発育に必要にして十分な種類と量のイオンを含んでいる。

Table 1. Basal medium employed for experiments on the NaCl requirement.

Ca-lactate	3.5 g
Peptone	2.0
L-Ascorbic acid	0.1
K_2HPO_4	0.2
$MgSO_4 \cdot 7H_2O$	2.5
$FeSO_4 \cdot 7H_2O$	0.2
Distilled water	1,000 ml
pH	7.5

ドウ糖溶液（海水とほぼ等張）に再懸濁し，さらに同じ溶液で 100 倍にうすめ，この液 1 滴を 10 ml の被検培地に接種した。得られた結果は第 2 表に示す通りである。

Table 2. Growth of sulfate-reducing bacteria on the media containing NaCl in various concentrations.

Strain number	Isolated from:	Concentration of NaCl (%)																		
		0	0.25	0.5	0.75	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
S M 1	Coastal marine sediment, Maizuru Bay	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
S M 2	〃	−	−	−	−	±	+	+	+	+	+	+	+	+	+	+	+	−	−	−
S M 3	〃	−	−	−	−	−	+	+	+	+	+	+	+	+	±	−	−	−	−	−
S M 4	〃	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−	−
S M 5	Coastal sea water, Maizuru Bay	−	−	−	±	+	+	+	+	+	+	+	+	+	+	+	±	−	−	−
S M 6	Brackish water, Takano River, Maizuru	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
S M 8	Coastal marine sediment, Maizuru Bay	−	−	−	−	−	+	+	+	+	+	+	+	+	±	−	−	−	−	−
S M 9	〃	−	−	−	−	−	±	+	+	+	+	+	+	+	+	±	−	−	−	−
S M10	〃	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−
S M11	Sediment on estuarine environments, Takano River, Maizuru	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
S M20	Coastal marine sediment, Maizuru Bay	−	−	−	−	+	+	+	+	+	+	+	+	+	+	+	−	−	−	−
S M21	〃	−	−	−	−	−	±	+	+	+	+	+	+	+	+	−	−	−	−	−
S M23	Coastal sea water, Maizuru Bay	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−	−
S M24	〃	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−
S M30	Coastal marine sediment, Shimonoseki	−	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	±	±
S M31	〃	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−
S M32	〃	−	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−
S M33	〃	−	−	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
S M34	〃	−	−	−	±	+	+	+	+	+	+	+	+	+	+	+	−	−	−	−
S M41-1	Sediment on estuarine environments, Nagata River, Shimonoseki	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−

SM41-2	〃	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−
SM42	〃	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
SM43	〃	−	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−
SM45	〃	−	−	−	−	−	+	+	+	+	+	+	+	+	+	±	−	−	−	−
SM46	Coastal marine mud, Shimonoseki	−	−	−	±	+	+	+	+	+	+	+	+	+	+	−	−	−	−	−
SM47	〃	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−
SM48	Coastal marine sediment, Shimonoseki	−	−	−	−	−	+	+	+	+	+	+	+	+	+	±	−	−	−	−
SM49	〃	−	−	−	−	−	+	+	+	+	+	+	+	+	+	−	−	−	−	−
SM410	Coastal marine mud, Shimonoseki	−	−	−	−	+	+	+	+	+	+	+	+	+	+	±	−	−	−	−
SM51	Coastal marine sediment, Mitajiri Bay	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
SM52-1	〃	−	−	±	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−	−
SM52-2	〃	−	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−	−
SM53-1	〃	−	−	−	−	−	+	+	+	+	+	+	+	+	+	−	−	−	−	−
SM53-2	〃	−	−	−	−	−	±	+	+	+	+	+	+	+	+	±	−	−	−	−
SM54	〃	−	−	−	−	−	+	+	+	+	+	+	+	+	±	−	−	−	−	−
SM55-1	〃	−	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−
SM55-2	〃	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−	−
SM56	〃	−	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−	−
SM57	〃	−	−	−	−	−	+	+	+	+	+	+	+	+	±	−	−	−	−	−
SM58	〃	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−	−
SM59	〃	−	−	−	−	−	−	+	+	+	+	+	+	+	−	−	−	−	−	−
SM510	〃	−	±	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−
SM511	〃	−	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
SM512-1	〃	−	−	−	−	+	+	+	+	+	+	+	+	+	+	±	−	−	−	−
SM512-2	〃	−	−	−	−	+	+	+	+	+	+	+	+	+	+	+	−	−	−	−
SM513	〃	−	−	−	±	+	+	+	+	+	+	+	+	+	+	+	−	−	−	−
SM514	〃	−	−	−	−	−	+	+	+	+	+	+	+	+	±	−	−	−	−	−
SM515-1	〃	−	−	−	−	+	+	+	+	+	+	+	+	+	+	±	−	−	−	−
SM515-2	〃	−	−	−	−	+	+	+	+	+	+	+	+	+	+	±	−	−	−	−
SH1	Coastal marine sediment, Hiroshima Bay	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	±	−
SK1	Offshore marine mud, Maizuru	−	−	−	−	−	+	+	+	+	+	+	+	+	+	−	−	−	−	−
SK2	Offshore sea water, Maizuru	−	−	−	−	−	+	+	+	+	+	+	+	+	+	−	−	−	−	−

すなわち，発育可能な食塩濃度範囲は菌株によってかなり異なり，SH1（食塩0.25〜7.5％）のように比較的広範囲にわたって発育できるもの，SM8（食塩1.5〜5.5％）のように比較的狭い範囲で発育するもの，およびSM1（食塩0.5〜7.0％）のように発育可能範囲がこれらの中間にあるものなどいろいろの程度の要求がみられた。これらの結果を集約すると第3表のとおりとなる。

すなわち，SH1のような比較的広塩性株は総分離菌株の9.6％を占めてもっとも少なく，SM8のような比較的狭塩性株は26.9％にあたり，残り63.5％はそれらの中間性を示した。そして，これら発育可能濃度範囲の広狭と，その棲息環境が海水域であったか汽水域であったかとの間には，なんら関連性がみられ

Table 3. Growth of sulfate-reducing bacteria on the media of various NaCl concentrations.

Concentration ranges of NaCl (%)	Strains developed	
	Number	%
From 0.25 to 7.5	5	9.6
From 0.5—1.0 to 6.0—7.0	33	63.5
From 1.5—2.0 to 5.5—6.0	14	26.9

なかった。

以上は食塩濃度についておこなった発育可能域の結果であるが，これは，食塩を加える代りにいろいろの程度に稀釈した海水で培地を調製して上と同様の方法で実験した第4表の結果とよく一致したから，上の結

Table 4. Growth of sulfate-reducing bacteria on the media containing sea water* in different strength.

Strain number	Strength of sea water** (%)								
	5	10	15	20	25	30	35	40	50
SM 1	−	−	−	±	+	+	+	+	+
SM 5	−	−	−	−	+	+	+	+	+
SM 8	−	−	−	−	−	−	−	−	+
SM 21	−	−	−	−	−	−	±	+	+
SM 33	−	−	−	−	−	+	+	+	+
SH 1	+	+	+	+	+	+	+	+	+
SK 1	−	−	−	−	−	−	−	−	+

* This was added in stead of distilled water contained in the basal medium.
** Salinity of original sea water was 32.4 g total salt per kg.

果は食塩濃度のみならず一般に塩分の要求性を十分反映しているものと考えられる。それ故，以下の実験では論議を簡単にするため食塩濃度のみについておこなうことにした。

(2) 海洋性硫酸塩還元細菌の発育速度および硫化物生成作用におよぼす食塩濃度の影響

(1) の結果，海洋性硫酸塩還元細菌の発育可能な食塩濃度の範囲が明らかになったが，つぎにこれらの細菌の発育速度ならびに硫化物生成作用が食塩濃度によってどのような影響を受けるかを検討した。

すなわち，第1表の組成の $FeSO_4 \cdot 7H_2O$ の代りに $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ 0.5 g/L* を含む基礎培地にいろいろの濃度の食塩を加え，これらに上の結果それぞれ塩分要求範囲を異にすることが判った SH1，SM1 および SM8 の純粋培養を少量接種し滅菌流動パラフィンを重層して 30°C に保ち，細菌数ならびに硫化物蓄積量を経時的に測定した。細菌数の測定は semi-solid 海水培地（330頁脚註参照）を用いて extinction dilution method により，硫化物の定量は富山・神崎の方法[5]によった。なお，これら菌株の相対的な発育速度ならびに硫酸塩還元速度の概略を比較するため，海水調製液体培地で 30°C 2日間ずつ3回

* 後報[4]のように，この細菌は Fe^{++} を発育に必須とし，ある範囲内ではこの量の多いほど発育速度は大きく，また生産された硫化物が安定である。そこでこの実験では，$FeSO_4$ よりも一般に安定と考えられる $Fe(NH_4)_2(SO_4)_2$ を用い，またその量を増すことにした。

Table 5. Growth of strain S H 1 and the production of sulfides at 30°C in the media having different salinity.

Concentration of NaCl (%)	Incubation time (hrs.)					
	20		41.5		65.5	
	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
0	10^2—10^3	0	10^2—10^3	0	1—10	0
0.25	10^2—10^3	0	10^2—10^3	0	10—10^2	0
0.5	10^4—10^5	0	10^3—10^4	0	10^6—10^7	0.027
1.0	10^5—10^6	trace*	10^6—10^7	0.029	10^9—10^{10}	0.162
1.5	10^6—10^7	trace	10^7—10^8	0.039	10^9—10^{10}	0.197
2.0	10^6—10^7	trace	10^7—10^8	0.044	10^9—10^{10}	0.241
2.5	10^4—10^5	0	10^7—10^8	0.029	10^9—10^{10}	0.210
3.0	10^3—10^4	0	10^6—10^7	0.021	10^8—10^9	0.154
3.5	10^4—10^5	0	10^5—10^6	0.025	10^9—10^{10}	0.115
4.0	10^3—10^4	0	10^5—10^6	0.008	10^8—10^9	0.069
4.5	—	0	10^4—10^5	0	10^7—10^8	0.038
5.0	—	0	10^4—10^5	0	10^6—10^7	0.015
5.5	—	0	10^4—10^5	0	10^5—10^6	0.010
6.0	10^3—10^4	0	10^4—10^5	0	10^6—10^7	trace
6.5	—	0	10^3—10^4	0	——	0
7.0	—	0	10^2—10^3	0	10^2—10^3	0
7.5	—	0	10^2—10^3	0	——	0
8.0	10^3—10^4	0	10^2—10^3	0	1—10	0

Incubation time (hrs.)					
89.5		141		237	
Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
——	0	0	0	——	0
——	0	1—10	0	——	0
10^6—10^7	0.023	10^6—10^7	0.025	10^5—10^6	trace
10^9—10^{10}	0.202	10^9—10^{10}	0.163	——	——
10^8—10^9	0.205	10^9—10^{10}	0.137	——	——
10^9—10^{10}	0.212	10^9—10^{10}	0.177	10^4—10^5	0.031
10^9—10^{10}	0.222	10^9—10^{10}	0.151	——	——
10^9—10^{10}	0.217	10^8—10^9	0.154	10^5—10^6	0.057
10^9—10^{10}	0.211	10^9—10^{10}	0.182	——	——
10^9—10^{10}	0.172	10^8—10^9	0.215	——	——
10^8—10^9	0.143	10^9—10^{10}	0.203	——	——
10^7—10^8	0.068	10^9—10^{10}	0.210	——	——
10^7—10^8	0.019	10^8—10^9	0.207	——	——
10^6—10^7	0.017	10^7—10^8	0.124	——	——
10^6—10^7	0.004	10^7—10^8	0.073	——	——
——	0	10^5—10^6	0.012	10^5—10^6	0.035
——	0	10^5—10^6	0.005	10^5—10^6	0.029
——	0	1—10	0	10^6—10^7	0.011

* trace: less than 0.001 mg/ml.

Table 6. Growth of strain S M 1 and the production of sulfides at 30°C in the media having different salinity.

Concentration of NaCl (%)	Incubation time (hrs.)					
	20		37		62.5	
	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
0	10^2—10^3	0	1—10	0	——	0
0.5	10^3—10^4	0	10^3—10^4	0	——	0
1.0	10^3—10^4	0	10^6—10^7	0	10^9—10^{10}	0.118
1.5	10^6—10^7	0	10^9—10^{10}	0.102	10^9—10^{10}	0.209
2.0	10^8—10^9	0	10^9—10^{10}	0.148	10^8—10^9	0.231
2.5	10^8—10^9	trace	10^9—10^{10}	0.204	10^9—10^{10}	0.254
3.0	10^8—10^9	trace	10^9—10^{10}	0.211	10^9—10^{10}	0.262
3.5	10^8—10^9	0	10^9—10^{10}	0.192	10^9—10^{10}	0.252
4.0	10^7—10^8	0	10^9—10^{10}	0.156	10^8—10^9	0.242
4.5	10^5—10^6	0	10^9—10^{10}	0.062	10^9—10^{10}	0.241
5.0	10^5—10^6	0	10^9—10^{10}	0.016	10^9—10^{10}	0.246
5.5	10^5—10^6	0	10^7—10^8	0	10^9—10^{10}	0.046
6.0	10^4—10^5	0	10^6—10^7	0	10^9—10^{10}	0.016
6.5	10^4—10^5	0	10^4—10^5	0	10^7—10^8	trace
7.0	10^4—10^5	0	10^4—10^5	0	10^5—10^6	0
7.5	10^4—10^5	0	10^3—10^4	0	——	0
8.0	10^3—10^4	0	10^3—10^4	0	——	0

Incubation time (hrs.)							
110.5		138.0		159.5		211	
Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
0	0	——	——	——	——	0	0
——	0	——	——	——	——	0	0
10^9—10^{10}	0.222	——	——	——	——	10^9—10^{10}	0.124
——	0.189	——	——	——	——	——	——
——	0.204	——	——	——	——	——	——
——	0.174	——	——	——	——	——	——
10^9—10^{10}	0.202	——	——	——	——	10^8—10^9	0.109
——	0.184	——	——	——	——	——	——
——	0.201	——	——	——	——	——	——
——	0.206	——	——	——	——	——	——
——	0.177	——	——	——	——	——	——
——	0.204	——	——	——	——	——	——
10^8—10^9	0.222	——	——	——	——	10^9—10^{10}	0.186
10^7—10^8	0.037	10^7—10^8	0.055	——	0.067	10^9—10^{10}	0.110
10^7—10^8	trace	10^7—10^8	0.017	10^8—10^9	0.024	10^8—10^9	0.045
——	0	——	——	10 —10^2	0	1 —10	0
10^3—10^4	0	——	——	——	——	1 —10	0

Table 7. Growth of strain S M 8 and the production of sulfides at 30°C in the media having different salinity.

Concentration of NaCl (%)	Incubation time (hrs.)							
	45		69		94		145	
	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
0	10^2—10^3	0	10 —10^2	0	——	0	0	0
0.5	——	0	10 —10^2	0	——	0	——	0
1.0	10^3—10^4	0	10^3—10^4	0	——	0	0	0
1.5	10^7—10^8	0.009	10^7—10^8	0.035	10^8—10^9	0.066	10^7—10^8	0.072
2.0	10^6—10^7	0.017	10^7—10^8	0.041	10^9—10^{10}	0.109	10^9—10^{10}	0.174
2.5	10^7—10^8	0.023	10^7—10^8	0.038	10^9—10^{10}	0.176	10^8—10^9	0.129
3.0	10^7—10^8	0.029	10^8—10^9	0.045	10^9—10^{10}	0.159	10^9—10^{10}	0.144
3.5	10^6—10^7	0.018	10^7—10^8	0.031	10^8—10^9	0.043	10^9—10^{10}	0.135
4.0	10^6—10^7	0.005	10^7—10^8	0.021	10^7—10^8	0.026	10^8—10^9	0.107
4.5	10^6—10^7	trace	10^5—10^6	0.017	10^7—10^8	0.037	10^7—10^8	0.068
5.0	10^3—10^4	0	10^3—10^4	0	——	0	10 —10^2	0
5.5	——	0	——	0	——	0	——	0
6.0	10^3—10^4	0	10^3—10^4	0	——	0	10 —10^2	0
6.5	——	0	——	0	——	0	——	0
7.0	10^2—10^3	0	10^3—10^4	0	——	0	0	0
7.5	——	0	——	0	——	0	——	0
8.0	10^3—10^4	0	10^2—10^3	0	——	0	0	0

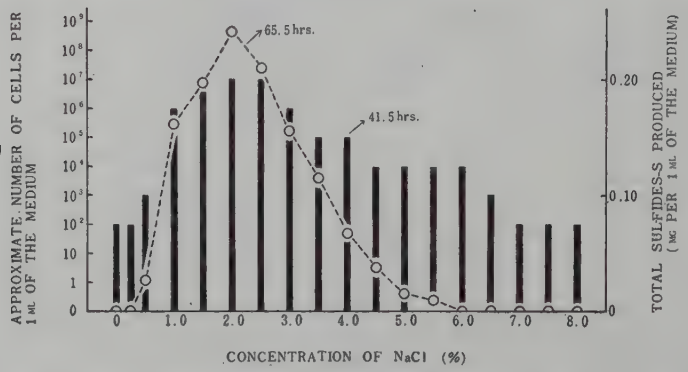


Fig. 1. Effect of NaCl concentration on the growth and sulfide production by strain SH1 at 30°C. ——: cells ; --○--: sulfides.

にわたって連続継代培養したものを接種に供した*。また接種に当っては，前培養を 2,500 r.p.m. 10 分で

* これらの細菌の発育ならびに硫酸塩還元作用は前培養での age の影響を敏感に受け，比較的 young な前培養を接種したときにはこれらの lag period が短かく且つ硫化物の最高値が大きいが，old な前培養による場合はこれらの lag period が長く且つ最高値が小さくなる傾向がある。

遠心集菌し，滅菌された 1.1 M ブドウ糖溶液（L-ascorbic acid 0.1 g/L を含む）で2回洗滌しこれに再懸濁した後，懸濁液 10^{-4} ml を被検培地 90 ml に接種した。それらの結果は第5，6および7表，ならびに第1，2および3図に示す通りである。

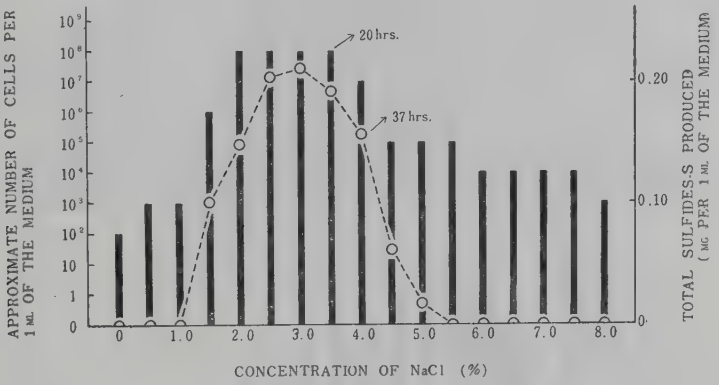


Fig. 2. Effect of NaCl concentration on the growth and sulfide production by strain SM1 at 30°C. ——: cells ; --○--: sulfides.

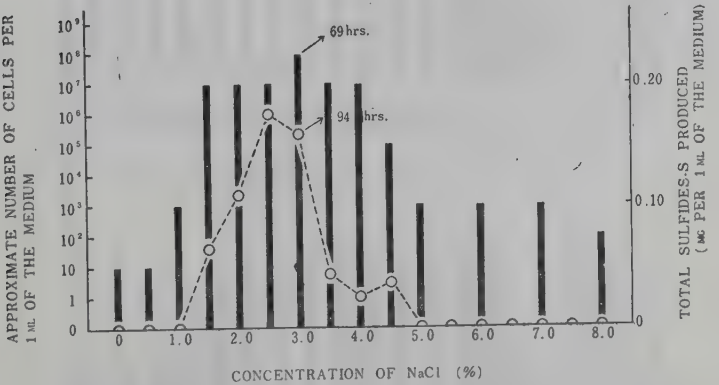


Fig. 3. Effect of NaCl concentration on the growth and sulfide production by strain SM8 at 30°C. ——: cells ; --○--: sulfides.

すなわち，いずれの菌株においても，発育ならびに硫酸塩還元作用がおこなわれた食塩濃度範囲は（1）においてみられた発育可能域にほぼ一致した。そして，それらの至適食塩濃度は，SH1については 1.5～2.5％付近，SM1については2.5～3.5％付近，SM8については2.5～3.0％付近とみられ菌株によって多少異なるようであるが，これらがいずれも典型的海洋性種であることを示している。

至適食塩濃度付近における発育速度，硫酸塩還元の activity ならびに硫化物の最高蓄積量（生産と，空気中への逸散ならびに酸化による消失との間の平衡にもとずくと考えられる）はSM1において最も大きくSH1ではいく分小さかったが，SM8においては前2者における よりもかなり低かった。また，いずれの

菌株においても，至適値から遠ざかった食塩濃度下では最高菌数および硫化物最高蓄積量は概して低い値に止まった。

（3）海洋性硫酸塩還元細菌の population 中における，食塩要求程度を異にする細菌の分布状態

一般に，一群の生物が物理学的・化学的刺激によって影響を受けるとき，その程度はすべての個体について一様ではなく，感受性には個体差がみられるのが普通である。

海洋性硫酸塩還元細菌が，河口付近または大量の工場廃水が海へ放出される排水口付近のような，海水と低鹹水または高鹹水とが交錯する水域にあるとき，環境塩分濃度の急変によってその生育能力はどのような影響を受けるであろうか。これを推察するための基礎的実験として，まずこの細菌の normal population 中にはいろいろの程度の食塩要求性（あるいは耐性）をもつ細菌がそれぞれどのように分布しているかを観察し，さらに前培養における training によってこの分布状態にどのような変化がおこるかをみた。

まず，塩分要求範囲の異なるSH1, SM1およびSM8の3株をそれぞれ海水調製の液体培地（330頁脚

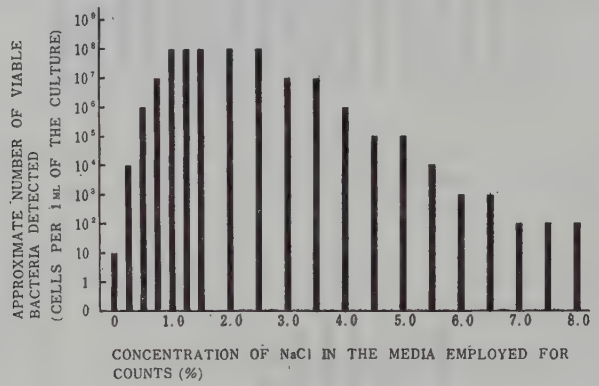


Fig. 4. Number of viable cells in the normal population of strain SH1 which were detected by use of the media having different salinity.

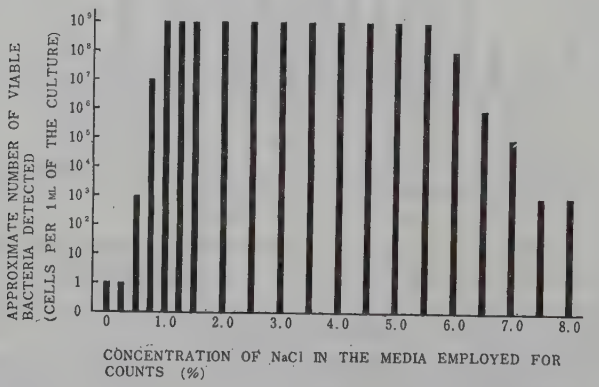


Fig. 5. Number of viable cells in the normal population of strain SM1 which were detected by use of the media having different salinity.

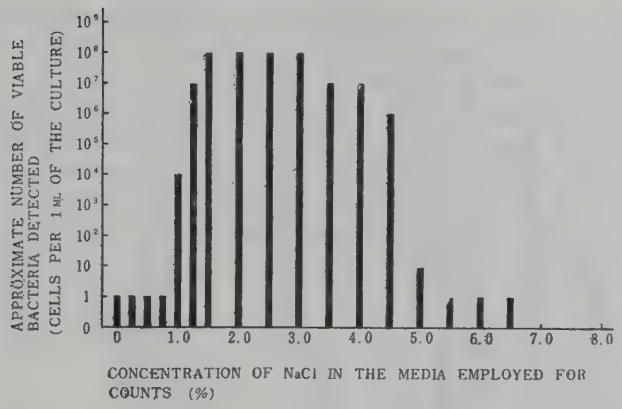


Fig. 6. Number of viable cells in the normal population of strain SM8 which were detected by use of the media having different salinity.

註参照）に 30°C で3日間前培養し，これらを，第1表の基礎培地に種々の濃度の食塩と寒天 3.0 g/L とを加えた培地を用いて，extinction dilution method で計数した。稀釈には，それぞれ相当する濃度の食塩水を用いた。その結果を第4，5および6図に示す。

すなわち，（1）において 0.25～7.5 %にわたる比較的広塩性を示したSH1は食塩 1.0～2.5 %で最高計数値（10^8/ml）を示し，これを離れるほど計数値は低くなったが，発育可能範囲外の食塩 0 %および 8.0 %においても，なおそれぞれ 10/ml および 10^2/ml を示した。一方，（1）において 1.5～5.5 %の比較的狭塩性を示したSM8は食塩 1.5～3.0 %において最高計数値 10^8/ml を示し，これを離れると計数値は急激に低くなったが，発育不可能域である 1.0 %においても 10^4/ml の比較的高い値があらわれた。また（1）において食塩 0.5～7.0 %を発育可能範囲として上の両者の中間の要求性を示したSM1では 1.0～5.5 %において最高計数 10^9/ml が得られたが，発育不可能域である 0 %および 0.25 %において 1/ml が，また 7.5 %および 8.0 %において 10^3/ml の値がそれぞれ示された。

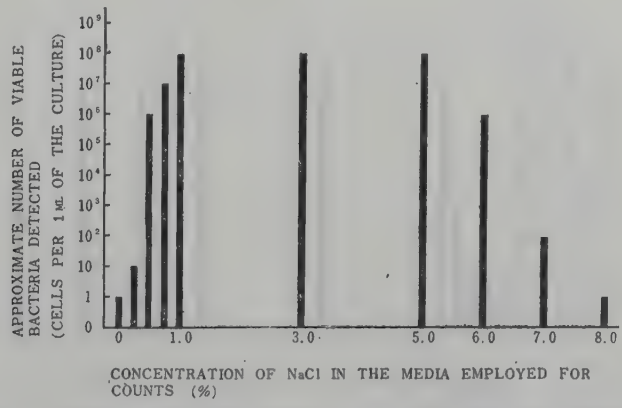


Fig. 7. Number of viable cells detected by use of the media having different salinity, in the population of strain SM1 which was preliminarily cultured in the medium containing 0.5 % NaCl.

これらの計数値は，おそらく normal population 中のそれぞれの食塩濃度で発育できる細菌数を表わすものとみられるが，これらの示す傾向は（1）および（2）で得られた結果と大体よく対応し，それぞれの菌株の食塩要求性（あるいは耐性）の特徴を裏書きしているようにみえる。

つぎに，中等度の食塩要求性を示したSM1についての計数（第5図）において，比較的低い食塩濃度（0.5および1.0％）と高い食塩濃度（6.0および7.0％）で発育した最高稀釈度の培養について，それぞれ引き続き上と同様に再び分布をしらべた。その結果は第7,8,9および10図に示すとおりである。

すなわち，0.5 または 1.0 % の低濃度食塩培地で前培養された population 中には，original culture（第5図）にくらべて低濃度食塩要求菌数が多く高濃度食塩耐性菌数が少なくなる傾向が示され，一方，6.0 または 7.0 %の高濃度食塩培地で前培養されたものでは，original culture にくらべて高濃度食塩耐性菌

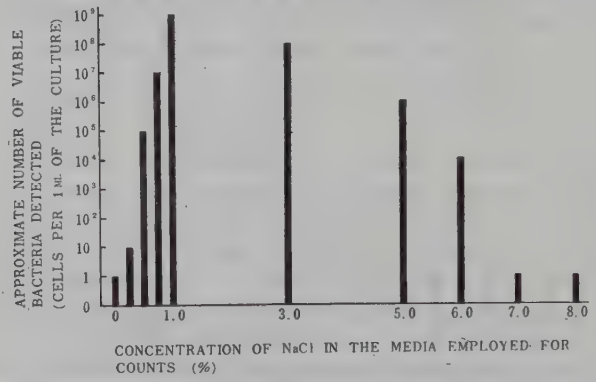


Fig. 8. Number of viable cells detected by use of the media having different salinity, in the population of strain SM1 which was preliminarily cultured in the medium containing 1.0 % NaCl.

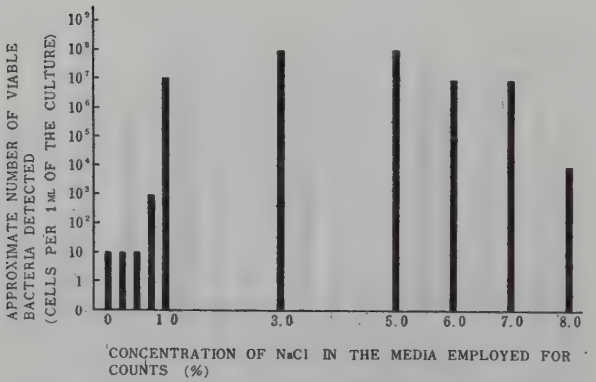


Fig. 9. Number of viable cells detected by use of the media having different salinity, in the population of strain SM1 which was preliminarily cultured in the medium containing 6.0 % NaCl.

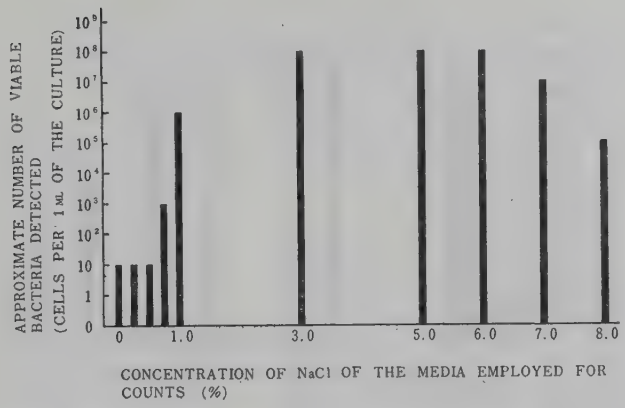


Fig. 10. Number of viable cells detected by use of the media having different salinity, in the population of strain SM1 which was preliminarily cultured in the medium containing 7.0 % NaCl.

数が多く低濃度食塩要求菌数が少なくなる傾向があらわれた。

またさらに，SM1を0.5または7.0%の食塩培地に約20代にわたって継代培養し，同じ食塩濃度培地を用いて再分離して，上と同様に食塩要求性の分布をしらべた。その結果は第11および12図に示される通り，0.5%食塩培地で馴致，再分離されたものは低濃度食塩要求菌数が多く高濃度食塩耐性菌数が少なくなる傾向が上より一層強くあらわれたが，7.0%食塩培地での再分離菌株は上の傾向がかえって弱められた。

以上2つの実験結果から，この細菌の食塩要求性（あるいは耐性）は training によってある程度までは比較的容易に順応できるが，極端な程度の適応は容易には起り得ないと考えられる。そして，どの培養においても食塩要求性の分布状態が前培養における食塩濃度付近に集中することなく original culture におけるものにほぼ近似したことから，以上の実験での計数値は固定された食塩要求性（または耐性）をもつある

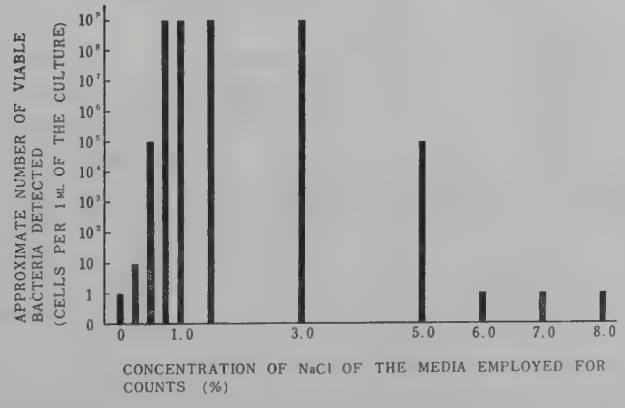


Fig. 11. Number of viable cells detected by use of the media having different salinity, in the secondary strain which was re-isolated from strain SM1 by use of the medium containing 0.5 % NaCl.

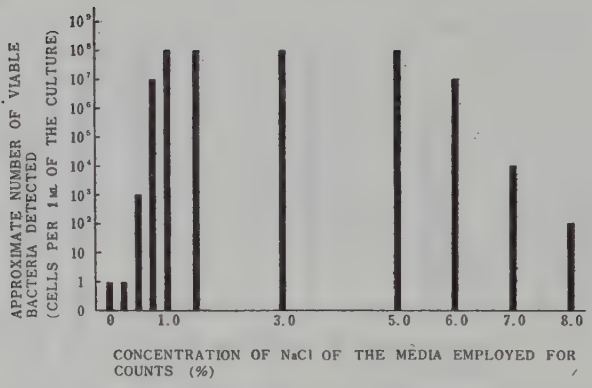


Fig. 12. Number of viable cells detected by use of the media having different salinity, in the secondary strain which was re-isolated from strain SM1 by use of the medium containing 7.0 % NaCl.

特別な細菌の数をあらわすものではなく，1つの population 中における食塩要求性についての個体変異の幅と高さを示すものであると思われる。

（4）海洋性硫酸塩還元細菌が各種滲透圧溶液と接触した後の生育能力

以上は発育中の細菌の食塩濃度に対する態度について行なった実験であったが，つぎに，この細菌がいろいろの滲透圧の溶液と接触したとき，その後の生育能力にどのような変化がおこるかを検討した。その方法はつぎの通りである。

海水調製の液体培地で 30°C に2日間前培養された SM1 の培養を，4,200 r.p.m. 10分で遠心集菌し，滅菌した蒸溜水，1.1 M ブドウ糖溶液，海水および 0.3，3.0 または 8.0 %食塩水（すべて L-ascorbic acid 0.1g/L を含む）に再懸濁させて 30 分間放置した後，0.5，3.0 および 8.0 %の食塩培地で計数した。稀釈にはそれぞれ相当する食塩水を用いた。また，一部は以上の集菌，懸濁，放置を2回繰り返した後計数した。それらの結果は第 13 図に示すとおりである。

すなわち，1回処理した場合には，海水および 3.0 %食塩水では original population におけるものと全く等しいか，またはそれを上回る計数値を示し，海水と等張である 1.1 M ブドウ糖溶液でもほとんど同様の計数値が得られたが，8.0 %および 0.5% 食塩水ではかなり低くあらわれ蒸溜水ではさらに著しく減少した。2回処理した場合には，海水では original population におけるのと同じ値が示され 3.0 %食塩水でもほぼ同様であったが，8.0 %食塩水，1.1 M ブドウ糖溶液，0.5 % 食塩水ではこの順序にしたがってはなはだしく減少し，蒸溜水では 3.0 % 食塩培地での計数が 10^5/ml を示したに過ぎずその他の培地では計数値0となった。

以上の結果から，この細菌が海水とほぼ等張である 3.0 %付近の食塩水または 1.1 M ブドウ糖溶液と短時間接触してもその後の生育能力はほとんど損なわれないが，0.3 %または 8.0 %付近の低張または高張溶液と接触するとそのうちの相当数の生育能力が失なわれ，蒸溜水ではこれが極めて著しいことが明らかになった。しかし蒸溜水の場合においてさえも，短時間（30分程度）の接触のみでは，なおかなりのもの（original population の $1/_{100}$ 程度）の生育能力が保存されていることが示された。また，海水とほぼ等張である 3.0 %食塩水および 1.1 M ブドウ糖溶液では海水での処理にくらべて幾分計数値が低くあらわれたことは，海水中にはこの細菌の生存に対して滲透圧の調節以外にある種の補助的要因が存在することを想像させる。

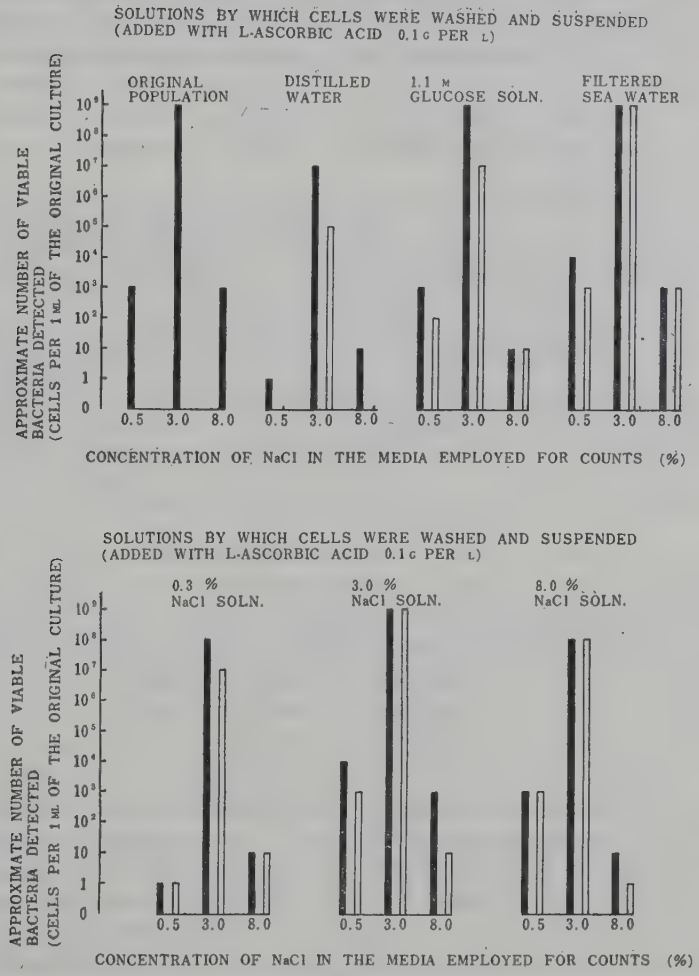


Fig. 13. Number of viable cells detected by use of the media containing different concentrations of NaCl, in the culture of strain SM1 after washed and suspended in solutions having different osmotic pressure. ▬▬ : treated once; ▭ : treated twice.

論　　議

実験（1）の通り，各地の土として沿岸海域および汽水域から海水培地を用いて分離された硫酸塩還元細菌は，菌株によって発育できる食塩濃度範囲を多少異にし比較的広塩性から狭塩性にいたるいろいろの程度の要求がみられたが，その多くは一般には1.0～6.5％付近を発育可能範囲とするもののようであった。そ

して，これらの中には食塩0.25％（あるいは海水強度 5％）付近の低塩分濃度でも発育できるものが若干存在したが，発育に全く食塩を必要としないものは見出されず，一方8.0％以上の食塩濃度で発育できる耐塩性種も存在しなかった。また，実験（2）の結果，これらは発育および硫酸塩還元作用の至適食塩濃度を概して2.0～3.0％付近とする典型的な海洋性種であることが明らかになった。これらのことは，MILLER[6]およびLITTLEWOOD・POSTGATE[7]がそれぞれ塩水，海水または淡水から分離した硫酸塩還元細菌の多くは食塩1％を発育至適濃度としたと報告していることと甚だ異なるが，彼らが用いた基礎培地* 中にはNa塩，塩化物など解離し得る水溶性塩類を高濃度に含んでいたから，実際の食塩濃度（あるいは塩分濃度）はこれより遙かに高い値となる。

硫酸塩還元細菌の塩分要求については，その他多数の研究者によって広範囲にわたる異なった結果が報告されている（ZOBELL[8]によって綜述されている）が，以上のことから考えると沿岸海域および河口付近の汽水域に棲息する硫酸塩還元細菌は（淡水性種は別として）ほとんど典型的海洋性種とみなされ，極端な広塩性種はたとえあるとしても極めて稀にしか存在しないのではなかろうか。

既報[1]において淡水の影響がほとんどない純海水域にも淡水培地に発育できるものが少数見出されたが，実験（3）の結果と照らし合わせると，極端な広塩性種の存在というよりも，むしろ海洋性種の normal population 中の低塩分要求性菌がこの培地に出てきた可能性がつよい。すなわち，ここに用いた extinction dilution counts によるときは，ことに稀釈率の低いところでは，サンプルからの塩分の導入を無視できないからである。このことはまた，上の海水域から淡水培地に生育できる粗培養を得て同じ培地に継代培養したとき，大量を接種しないと発育できず，しかもその多くは数代のうちに消失したことからもうかがわれる。

実験（3）の結果は，normal population 中に通常の発育可能範囲を越えて低いまたは高い食塩濃度に発育できる細菌が少数存在することを示し，はなはだ奇異の感を与える。しかし，この理由はおそらくつぎのように考えられる。すなわち，この計数法では低い稀釈度においては前述のようにサンプルである前培養（この場合は海水培地）からの塩分が計数培地へ導入されるのをまぬがれないから，1～10/ml のような低い計数値を与えたものについては，その計数培地中の真の塩分濃度が所定濃度よりも高くまたは低くなっていたためであろう。あるいはまた，発育可能範囲を求めた実験（1）では接種量が少なかったため，上述のような細菌が含まれていなかったのか，または増殖開始に必要な菌量に達しなかったからであろう。

つぎに，これら食塩要求の程度を異にする population の分布状態は，（3）にみられるように前培養での食塩濃度によって影響を受け，分布が示す個体変異の中心が前培養培地の食塩濃度の方向へいく分移動することがみられ，ある程度食塩濃度に適応できることを示した。しかし，極端に低濃度または高濃度の食塩培地で流汰培養を繰り返した後この培地で再分離した場合にも，original culture から極端にかけはなれた結果は得られなかった。この事実は，trained culture について耐塩性の著しい適応をみた LITTLEWOOD・POSTGATE[7]の結果とは異なり，ZOBELL[8]が指摘しているように，塩分要求のはなはだしい適応が容易には起り難いことを意味し，また正常な発育環境よりも低張または高張のもとで培養することは塩分要求変異種を選択する働らきはあっても変異助長作用はないことを示すものであろう。

実験（4）の結果から，これらの細菌が本来の棲息環境よりも低張または高張の溶液と短時間接触したとき，その後の生育能力はかなり損なわれるが，蒸溜水のような極端な低張液あるいは8.0％食塩水のようなはなはだしい高張液と接触したときにも，なお相当の生育能力が残されていることがみられた。天然の環境下では，陸水や廃液の供給を受ける場合にもこの細菌の棲息地である底土中へは直接的影響が比較的および難いであろうということを考え合わせると，この生育能力の保存はさらに大きいことが想像される。

---

* たとえば MILLER[6] の用いた基礎培地はつぎのとおりである。NH_4Cl 1.00 g, $MgSO_4 \cdot 7H_2O$ 2.00 g, Na_2SO_4 36.50 g, K_2HPO_4 0.50 g, $CaCl_2 \cdot 2H_2O$ 1.70 g, Sodium lactate 21.00 g, $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ trace, Distilled water 1,000 ml.

なお，SM1の菌株はさきに筆者が他の協同研究者とともに実験に供したものであって，これの発育ならびに硫化物生成作用と塩分濃度との関係についてはすでに概略を報告した[8]。本報での結果は既報のものとは詳細の点で多少異なるが，これは後者では海水を稀釈または濃縮して供試培地としたから基質である硫酸塩をはじめ食塩以外の塩類濃度の影響をまぬがれなかったためと思われる。

摘　　要

各地の，主として沿岸海域および汽水域から海水培地を用いて分離された硫酸塩還元細菌の，発育および硫酸塩還元作用と食塩濃度との関係を調べつぎの結果を得た。

1. これらの細菌の大部分は食塩1.0～6.5％付近を発育可能範囲とし，それより低濃度または高濃度で発育できるものは僅かに過ぎなかった。
2. これらの細菌の発育および硫化物生成作用は，概して食塩2.0～3.0％付近を至適濃度とした。
3. これらの細菌の純粋培養の normal population 中には，上の発育可能範囲を越えて，より低濃度またはより高濃度で生育できるものが少数存在した。
4. これら population 中における異なった食塩濃度に生育できる細菌数の分布状態から，これらの細菌は正常な発育環境より低張または高張の環境にある程度適応して発育できるが，極端な適応または変異はおこり難いことを推論した。
5. これらの細菌が正常な棲息環境より低張または高張の環境下に短時間おかれたとき，その後の生育能力はかなり損なわれるが，なお相当数が生育能力を保つことを推定した。

本研究にあたり，ご指導いただいた京都大学農学部木俣正夫教授，およびご指導ならびにご校閲いただいた京都大学食糧科学研究所門田　元教授に厚くお礼申し上げる。また，細菌の分離に際し試料泥土の一部を採集していただいた本所赤築敬一郎助教授に深謝する。

文　　献

1) 木俣正夫・門田　元・畑　幸彦・三好英夫：1957．日本水産学会誌，**22**，701—707.
Masao KIMATA, Hajime KADOTA, Yoshihiko HATA and Hideo MIYOSHI : 1958. *Records Oceanogr. Works Japan*, Special No. **2**, 187—199.
2) 木俣正夫・門田　元・畑　幸彦・田島卓明：1955．日本水産学会誌，**21**，109—112.
3) 畑　　幸彦：1960．本報告，**9**，347—362.
4) 畑　　幸彦：1960．本報告，**9**，363—375.
5) 富山哲夫・神崎嘉瑞夫：1951．日本水産学会誌，**17**，115—121.
6) MILLER L.P. : 1949. *Contr. Boyce Thompson Inst.*, **15**, 437—465.
7) LITTLEWOOD, D., J.R. POSTGATE : 1957. *J. gen. Microbiol.*, **17**, 378—389.
8) ZOBELL, C.E. : 1958. "Ecology of Sulfate Reducing Bacteria." *Producers Monthly*, **22**, 12—29.

海洋性硫酸塩還元細菌の無機塩要求について※

畑　　幸彦

Inorganic Nutrition of Marine Sulfate-Reducing Bacteria※

By

Yoshihiko HATA

The author has previously reported that a majority of marine sulfate-reducing bacteria which were isolated from marine or estuarine environments could grow in the media containing NaCl in the concentrations of nearly 1.0—6.5 % (the optimum was 2.0—3.0 %).

In the present paper the author studied in detail the inorganic nutritional requirements of these bacteria.

As the test organisms marine sulfate-reducing bacteria strain SM1 was used throughout the study. Peptone and lactic acid added to the chemically defined basal medium, as shown in Table 1, which was employed in these experiments were demineralized by passage through the columns of ion exchange resins "Permutit H—70" (H—form) and "Permutit A" (OH—form). The solutions having the composition as shown in Tables 2 or 6 were employed as the standard salts mixtures.

The results obtained are shown in Tables 3—18, and may be summarized as follows:

1) Na^+, K^+, Mg^{++} and SO_4^{--} were essential for the growth of these bacteria, and Cl^-, HCO_3^- and PO_4^{---} also seemed to be necessary for the growth. On the other hand, Ca^{++} and Br^- were not essentially required for the growth and the sulfate-reducing activity of these organisms.
2) The amounts of the essential ions required for the growth were relatively small, and these ions could partially be replaced each other.
3) When these essential ions were sufficiently or excessively present the growth and the sulfate-reducing activity of these organisms were often influenced by the osmotic pressure of the media.

※ 水産講習所研究業績　第304号,　1960年2月11日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 304.
Received Feb. 11, 1960.

前報[1]において，いろいろの水域から分離された硫酸塩還元細菌の発育ならびに硫化物生成作用におよぼす食塩濃度の影響を明らかにした。また既報[2]において筆者は，他の協同研究者とともに，この細菌の発育に Mg^{++} および Fe^{++} が不可欠であることを報告した。

硫酸塩還元細菌の発育に対する無機塩類の影響に関しては，BUTLIN・ADAMS・THOMAS[3] および POSTGATE[4] は Fe^{++} についてその必要性を認め，また MILLER[5] は Fe^{++} または Cd, Sb, Bi および Pb などの比較的難溶性塩類が存在するとこの細菌の硫化物生成作用が促進されることを明らかにした。UPDEGRAFF・WREN[6] は硫酸塩還元細菌の増殖に K^+, Mg^{++}, Fe^{++} および PO_4^{---} が必要であることを報告し，BAAS BECKING・WOOD[7] は2価カチオンに対する1価カチオンの比率あるいは Cl^-, HCO_3^- および SO_4^{--} の相対的濃度はこの細菌による硫酸塩の還元に対して決定的ではないこと，およびこの細菌は NaCl 濃度に対しては広範囲にわたって耐えられるが，$MgCl_2$ によっては 0.9 N 以上で発育が阻害されることを認めた。また，鈴木・志賀[8]は水田土壌中における遊離硫化水素の発生が種々の含鉄材によって抑制されることを述べ，菅原・小山[9]は湖底泥土中における硫酸塩の還元に対して Fe^{++} は促進的効果をもち Mn^{++} はこれと拮抗的に作用することを示した。また MACLEOD・ONOFREY[10] は数種の海洋性細菌の発育に対する Na^+, K^+, Ca^{++}, Mg^{++}, Fe^{++}, Cl^-, SO_4^{--} または PO_4^{---} の必要性について報告した。

しかし，海洋性硫酸塩還元細菌の発育ならびに activity に対する種々の無機塩類の影響についての系統的研究はなされておらず，詳細は全く不明である。前報[1]で明らかな通り，この細菌は典型的海洋性種であって一般細菌に比して高濃度の塩分を要求する点からも，このものの無機塩要求の実態を究明することは重要である。Fe など比較的原子量の大きい金属については後報[11]で述べることにし，本報では海水中の塩分の主成分である種々のカチオンならびにアニオンおよびこれらの塩類についてその必要性を明らかにし，さらにこれらイオン間における相互的関係について論じた。

実　験　方　法

1. 供試細菌：前報[1]で普通の塩分要求を示した SM 1 の菌株を用いた。

2. 接種ならびに培養：接種に際して前培養からの微量のイオンの導入を避けるため，あらかじめ海水液体培地[1]で 30°C 2日間前培養された菌体を 2,500 r.p.m. 10 分で遠心集菌し，0.1 g/L の L—ascorbic acid を含む滅菌された 1.1 M ブドウ糖溶液（海水とほぼ等張）で2回洗滌再懸濁し，この懸濁液 10^{-4} ml を 80 ml の被検培地に接種した。培養基には滅菌流動パラフィンを約 2 cm 重層して，硫化物の酸化，逸散を防いだ。また綿栓からの汚染を避けるためこれに綿布を巻いた。培養温度はすべて 30°C であった。

3. 培地の調製：細菌に対するイオンの必要性を明らかにするためには，そのイオンを含まない基礎培地を調製することが必須である。この細菌は既報[12]のように，無機塩類のみの合成培地では発育せず比較的多量の有機エネルギー源* および少量の含窒素有機物を発育に必要とするので，これらの有機物を含む天然培地から問題のイオンを除くことが肝要である。

有機物培地からのイオンの除去は極めて困難であるが，筆者は主として SHANKAR・BARD[13] および MACLEOD・ONOFREY[10] の方法を参考としてイオン交換樹脂 "Permutit"（The Permutit Co., N.Y., U.S.A.）を用いてつぎの方法で処理し，ほぼ満足な結果を得た。

すなわち，カチオンの除去には，0.5 N HCl で処理した "Permutit H—70" を直径 2.2 cm，長さ約 50 cm の硬質ガラス筒に填めてカラムをつくり，これにあらかじめ 15 ポンド 20 分間オートクレーブした第1表の組成の2倍濃度のペプトン・乳酸溶液（pH 7.0）を1分間 3 ml の速度で通す。最初の約 200 ml

* この細菌は facultative autotrophs の一つであって，少量の有機物の存在下では一部ヒドロゲナーゼによって分子状水素を被還元基質へ伝達することによりエネルギーを獲得できるが[12]，有機物培地にくらべて培養法が煩雑であり，かつ発育および硫酸塩還元作用がおくれるようである。

Table 1. Basal medium for the study of mineral requirements.

Peptone	2.0 g
Lactic acid	2.5
$(NH_4)_2\ HPO_4$	0.15
$Fe(NH_4)_2\ (SO_4)_2 \cdot 6H_2O$	0.5
L-Ascorbic acid	0.2
Salt solution	1,000 ml
pH 7.5	

は捨て残りをとる。これの pH を再修正して再びオートクレーブし，0.5 N HCl で再生した同じカラムを通す。また，アニオンの除去には，30 % NaOH で処理した "Permutit A" のカラムを上と同じ方法で通す。

以上の方法で処理したペプトン・乳酸溶液に他の必要な塩類を加え，蒸溜水で所定濃度に稀釈し，稀薄 NH_4OH および HCl (または H_2SO_4) で pH を調整し，15 ポンド 20 分間オートクレーブし再び pH を修正して供試培地とした。また，重炭酸塩およびブドウ糖は加熱滅菌による分解，変化を避けるためこれらの溶液を SEITZ 濾過器で滅菌後，無菌的に加えた。

またこの細菌は発育に本来海水調製の培地を必要とするが，無機塩の要求をしらべるためには化学的組成の明確な培地を選ぶことが必要であるから，実験にはすべて人工海水を用いた。人工海水の標準としては先ず LYMAN・FLEMING [14] のものに準じて第2表の組成のものを選んだが，実験の進むにつれて，この細

Table 2. Composition of artificial sea water employed as the standard mineral solution.

NaCl	23.48 g	(0.403 M)
$MgCl_2$	4.98	(0.052)
KCl	0.67	(0.009)
Na_2SO_4	3.92	(0.028)
$CaCl_2$	1.10	(0.010)
$NaHCO_3$	0.19	(0.002)
KBr	0.10	(0.001)
Distilled water	1,000 ml	

菌の最少要求を満たすに足るさらに簡単な第6表の組成のものを考案し，以後は主としてこれによった。

4. 試薬およびガラス器具：試薬は入手できる限りの最純品を用いた。ガラス器具はクロム硫酸混液を通し蒸溜水で洗滌後，0.5 N HNO_3 および 0.5 N NaOH で洗滌し蒸溜水を満たして 15 ポンド 20 分間オートクレーブし1昼夜放置後，さらに蒸溜水で数回洗滌した。

5. 蒸 溜 水：再溜水をさらにイオン交換装置 (Amberlite IR—120 および Amberlite IR—4 B) を通して純化した。

6. 発育および硫化物の測定：発育は semisolid 海水培地を用いて extinction dilution method により，硫化物は富山・神崎の方法[15]によった。

実 験 結 果

(1) 基礎培地の検討

上の方法で得られたイオン欠除の有機物培地がこの細菌の有機物要求を満たすか否か，また第2表の人工海水が天然海水を十分代用できるか否かをみるために，つぎの実験を行なった。

すなわち，未処理の有機物を含む培地，またはカチオンならびにアニオン除去処理の行なわれた有機物を含む培地を，天然海水または第2表の人工海水で調製し，細菌を接種して発育および硫化物生成作用をみた。その結果第3表の通り，どの培地においてもほとんど大差なく発育および硫酸塩還元作用が行なわれるこ

Table 3. Growth and sulfide production of sulfate-reducing bacteria strain SM 1 at 30°C in the media prepared with natural or artificial sea water which were treated or untreated with the ion exchange resin "Permutit".

Treatment with "Permutit H-70" and "Permutit A"	Basal sea water	Incubation time (hrs.)					
		24		46		72	
		Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
Treated	Artificial	10^5—10^6	0	10^9—10^{10}	0.087	10^9—10^{10}	0.146
Untreated	Artificial	10^5—10^6	0	10^9—10^{10}	0.069	10^9—10^{10}	0.112
Treated	Natural	10^6—10^7	0	10^8—10^9	0.099	10^9—10^{10}	0.138
Untreated	Natural	10^5—10^6	0	10^9—10^{10}	0.116	10^9—10^{10}	0.143

Incubation time (hrs.)					
94		117		141	
Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Sulfides -S mg/ml	
10^9—10^{10}	0.248	10^9—10^{10}	0.284	0.262	
10^9—10^{10}	0.251	10^9—10^{10}	0.292	0.237	
10^9—10^{10}	0.244	10^9—10^{10}	0.295	0.237	
10^9—10^{10}	0.234	10^9—10^{10}	0.280	0.245	

とが示された。すなわち，上の方法によってペプトン・乳酸を処理してもこの細菌の有機物要求は十分満たされること，および第2表の人工海水は天然海水にほとんど匹敵することが明らかになった。したがって以下の実験においては，この処理によってイオン欠除とした有機物培地を，第2表の人工海水で調製したものをもって標準完全培地とすることにした。

(2) Na^+, K^+, Ca^{++} および Mg^{++} の必要性

海水中の主要なカチオンである Na^+, K^+, Ca^{++} および Mg^{++} の必要性を明らかにするため，完全人工海水からこれらのイオンをそれぞれ単独に除いて培地を調製し，発育および硫化物生成作用をみた。この場合，被検カチオンの塩類を除くことによって随伴アニオンが同時に除かれるから，他の塩類を加えてこれを補なった。また滲透圧を一定にそろえるため，ブドウ糖* を加えて調節した。その結果は第4表に示す通りである。

* 既報[12]の通り，この細菌は純粋培養においてはブドウ糖をエネルギー源として利用できないので，このもの自体の影響はない。

Table 4. Requirements of Na^+, K^+, Ca^{++} or Mg^{++} for the growth and the sulfate-reducing activity (SM 1).

Modification of artificial sea water* employed as the basal solution		Incubation time (hrs.)			
		72		144	
Omitted (M)	Added (M)	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml
Non	Non	10^9—10^{10}	0.146	10^9—10^{10}	0.332
NaCl(0.403), Na_2SO_4(0.028), $NaHCO_3$(0.002)	$(NH_4)_2SO_4$(0.028), Glucose (0.810)	10^4—10^5	0	10^3—10^4	0
NaCl(0.403), Na_2SO_4(0.028), $NaHCO_3$(0.002)	NH_4Cl(0.403), $(NH_4)_2SO_4$(0.028), $KHCO_3$(0.002)	10^4—10^5	0	10^3—10^4	0
NaCl(0.403), Na_2SO_4(0.028), $NaHCO_3$(0.002)	KCl(0.403), K_2SO_4(0.028), $KHCO_3$(0.002)	10^4—10^5	0	10^4—10^5	0
Na_2SO_4(0.028), $NaHCO_3$(0.002)	$(NH_4)_2SO_4$(0.028), NaCl(0.058)	10^9—10^{10}	0.133	10^9—10^{10}	0.257
NaCl(0.403), $NaHCO_3$(0.002)	Na_2SO_4(0.203)	10^9—10^{10}	0.118	10^9—10^{10}	0.432
KCl(0.009), KBr(0.001)	Glucose(0.020)	10^4—10^5	0	10^3—10^4	0
KCl(0.009), KBr(0.001)	NaCl(0.009), NaBr(0.001)	10^4—10^5	0	10^2—10^3	0
KBr(0.001)	KCl(0.001)	10^9—10^{10}	0.202	10^9—10^{10}	0.438
KCl(0.009)	KBr(0.009)	10^9—10^{10}	0.154	10^9—10^{10}	0.411
$CaCl_2$(0.010)	Glucose(0.030)	10^9—10^{10}	0.244	10^9—10^{10}	0.362
$CaCl_2$(0.010)	NH_4Cl(0.020)	10^9—10^{10}	0.149	10^8—10^9	0.317
$MgCl_2$(0.052)	Glucose(0.153)	10^4—10^5	0	10^4—10^5	0
$MgCl_2$(0.052)	NH_4Cl(0.104)	10^4—10^5	0	10^3—10^4	0
Non	Glucose(0.810)	10^7—10^8	0.018	10^9—10^{10}	0.422

* c.f. Table 2.

すなわち，Na^+ については，NaCl，Na_2SO_4 および $NaHCO_3$ をすべて除きこれらの代りにブドウ糖を加えるか，あるいはこれらの NH_4 塩または K塩を加えた場合には全く発育しなかったが，Na 塩をすべて NaCl または Na_2SO_4 でおきかえた場合には十分な発育と activity が示された。K^+ については，KCl および KBr を除きこれに匹敵する量のブドウ糖を加えるか，またはこれらの Na 塩を補なってもまったく発育せず，K塩をすべて KCl または KBr でおきかえると十分発育した。つぎに Ca^{++} については，これを除いてもブドウ糖または NH_4 塩を補なうと盛んに発育した。一方，Mg^{++} においては，これを除くとブウ糖または NH_4 塩を補なっても全く発育できなかった。

以上の結果から，Na^+，K^+ および Mg^{++} はこの細菌の発育に必須不可欠であるが，Ca^{++} の存在はほんど影響を与えないように思われる。そしてこれらの必要性は，これらイオンのおのおのを含むそれぞれ一種類の塩によってよく満たされることが明らかになった。

つぎに，この細菌の発育にとってこれら必須イオンが少なくともどの程度以上に存在することが必要かをみるために，第5表に示したいろいろの組成の人工海水培地で実験した。すなわち上の結果にもとずいて，第2表の人工海水の Na^+ を NaCl で，K^+ を KCl でそれぞれ代用し Ca^{++} を省いた。SO_4^{--} は $(NH_4)_2SO_4$ で補なった。また培地の滲透圧はブドウ糖を加えて等しく調節した。

その結果，Na^+ については，0.230 g atoms/L（通常の海水中における½程度）の濃度ではその速度はおそくとも十分発育できたが，0.046 g atoms/L（$\frac{1}{10}$程度）では全く発育できなかった。K^+ および Mg^{++} では，それぞれ 0.001 および 0.005 g atoms/L * （それぞれ$\frac{1}{10}$程度）の濃度でも十分な発育が得られたが，

* 既報[2]において，Mg^{++} は 0.0005 g atoms/L でこの細菌の発育を支え得ることを示した。

Table 5. Response of sulfate-reducing bacteria strain SM 1 to Na^+, K^+ and Mg^{++}.

Composition of salt solution employed for the preparation of culture media (M)					Incubation time (hrs.)					
					44		94		166	
NaCl	KCl	$MgCl_2$	$(NH_4)_2SO_4$	Glucose	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml
Standard * (Control)					10^5—10^6	0	10^9—10^{10}	0.150	——	0.224
0.460	0.010	0.052	0.028	0	10^7—10^8	0.019	10^9—10^{10}	0.080	——	0.234
0.230	0.010	0.052	0.028	0.460	10^4—10^5	0	10^9—10^{10}	0.060	——	0.230
0.046	0.010	0.052	0.028	0.820	10^2—10^3	0	0	0	——	0
0.460	0.005	0.052	0.028	0.010	10^6—10^7	0	10^9—10^{10}	0.053	——	0.213
0.460	0.001	0.052	0.028	0.020	10^6—10^7	0	10^9—10^{10}	0.081	——	0.231
0.460	0.010	0.026	0.028	0.070	10^7—10^8	0.017	10^9—10^{10}	0.074	——	0.256
0.460	0.010	0.005	0.028	0.160	10^7—10^8	0.020	10^8—10^9	0.073	10^9—10^{10}	0.264

* c. f. Table 2.

その速度は濃度によって多少の支配を受けた。

また，Ca^{++} の必要性については，さらにつぎの実験で確かめた。すなわち，以上の結果にもとずいて考案した第6表に示す簡単な人工海水で調製された基礎培地にいろいろの濃度の $CaCl_2$ を加えて培養したが，

Table 6. Composition of the simplified artificial sea water.

$(NH_4)_2SO_4$	3.63 g	(0.028 M)
NaCl	26.89	(0.460)
KCl	0.75	(0.010)
$MgCl_2$	4.98	(0.052)
Distilled water	1,000 ml	

Table 7. Effect of Ca^{++} on the growth and the sulfide producing activity of sulfate-reducing bacteria strain SM1. (Basal medium was prepared with the simplified artificial sea water*. Ca^{++} was added as $CaCl_2$.)

Concentration of Ca^{++} added (M)	Incubation time (hrs.)							
	24		47		64		112	
	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml
0	10^9—10^{10}	0.024	10^9—10^{10}	0.277	10^9—10^{10}	0.224	10^8—10^9	0.172
0.001	10^9—10^{10}	0.041	10^9—10^{10}	0.305	10^9—10^{10}	0.281	10^9—10^{10}	0.179
0.005	10^9—10^{10}	0.037	10^9—10^{10}	0.360	10^9—10^{10}	0.263	10^9—10^{10}	0.204
0.010	10^9—10^{10}	0.038	10^9—10^{10}	0.300	10^9—10^{10}	0.220	10^9—10^{10}	0.176
0.020	10^9—10^{10}	0.029	10^9—10^{10}	0.350	10^9—10^{10}	0.246	10^8—10^9	0.187

* c. f. Table 6.

第7表に示す通り Ca^{++} 0～0.020 g atoms/L の範囲内では Ca^{++} 添加の影響はほとんど現われなかった。さらに，Ca^{++} 欠除培地で継代培養しても発育および activity にはなんらの変化もおこらなかった。

結局，以上の諸実験の結果を総括すると，この細菌の発育にとって Na^+, K^+ および Mg^{++} は必須不可欠

であることは明らかであり，その発育は通常の海水中における量に比して少なくとも½程度の Na^+，$\frac{1}{10}$ 程度の K^+ および $\frac{1}{10}$ 程度の Mg^{++} で十分ささえられるが，その速度はこれら必須イオンの濃度によって多少とも影響を受けるものと思われる。また Ca^{++} については，この細菌にとっておそらく必須ではないか，あるいは極めてわずかにしか要求されず，その発育促進作用もほとんどないものと認められる。

また，上述の通り，この細菌の発育には第6表に示した比較的簡単な人工海水の培地で十分であることが明らかになったので，以下の実験では論議を簡単にするため，この組成を人工海水の基準とすることにした。

（3）Na^+ の必要性に対する K^+ の補償作用

実験（2）において，この細菌の発育には Na^+ が不可欠でありその必要量は他の必須イオンに比していく分大きいらしいということが示されたが，この場合 Na^+ の要求を K^+ によって一部代用できるか否か，さらに Na^+ の必要限界量はどの程度であるかを以下の実験でしらべた。

すなわち，基礎培地を第6表の組成から NaCl および KCl を除いた塩類溶液で調製し，これに第8表に示すいろいろの濃度の NaCl および KCl を加えた。これらの培地中における Na^+ と K^+ の g atoms の

Table 8. Response of sulfate-reducing bacteria strain SM 1 to Na^+ and K^+. (Basal medium was prepared with the simplified artificial sea water from which Na^+ and K^+ were omitted. Na^+ and K^+ were added as chlorides.)

Concentrations of Na^+ and K^+ added (M)		Incubation time (hrs.)								
		15		39		63		87		159
Na^+	K^+	Cells/ml	Sulfides −S mg/ml	Cells/ml	Sulfides −S mg/ml	Cells/ml	Sulfides −S mg/ml	Cells/ml	Sulfides −S mg/ml	Sulfides −S mg/ml
0	0.470	$10-10^2$	0	0	0	0	0	0	0	0
0.024	0.446	$10-10^2$	0	0	0	0	0	0	0	0
0.118	0.352	10^4-10^5	0	10^6-10^7	0	10^8-10^9	0.093	10^9-10^{10}	0.133	0.221
0.235	0.235	10^5-10^6	0	10^9-10^{10}	0.034	10^9-10^{10}	0.108	10^9-10^{10}	0.131	0.203
0.352	0.118	10^5-10^6	0	10^9-10^{10}	0.041	10^9-10^{10}	0.102	10^8-10^9	0.106	0.224
0.446	0.024	10^5-10^6	0	10^9-10^{10}	0.061	10^9-10^{10}	0.075	10^8-10^9	0.120	0.197
*0.460	*0.010	10^6-10^7	0	10^9-10^{10}	0.066	10^9-10^{10}	0.094	10^9-10^{10}	0.124	0.214
0.470	0	10^4-10^5	0	10^2-10^3	0	$10-10^2$	0	0	0	0

* The concentrations in natural sea water.

総和が常に通常の海水中におけるこれら両イオンの総和に等しくなるようにしたものである。その結果は表に示す通り，Na^+ 0.118～0.460 g atoms/L（Na^+ と K^+ の総和の 25～98 %）の範囲においては発育がみられたが，それより外ではまったく発育しなかった。発育速度および activity は Na^+ 0.118 g atoms/L においてかなり小さかったのを除いては，0.235～0.460 g atoms/L ではほとんど差が認められなかった。

つぎに，これと対比するため，Na^+ を NH_4^+ でいろいろの程度におきかえて同様に実験した結果は第9表に示す通りであって，Na^+ 0.023 g atoms/L では発育せず 0.115 g atoms/L 以上で発育がおこったが，この場合にはその速度が Na^+ 濃度によって大きな影響を受け，これとほぼ比例することが示された。

これら2つの結果を比較検討すると，前の実験における K^+ は単なる滲透圧の調節作用の他に，この細菌の Na^+ に対する要求を一部補償しているようにみえる。

さらに，Na^+ の必要限界量を K^+ との関係において見出すため，Na^+ および K^+ 欠除の基礎培地にいろいろの濃度の NaCl および KCl を加えて発育の有無およびその程度をみた。その結果は第10表に示す通り，K^+ が 0.001 g atoms/L（通常の海水中の $\frac{1}{10}$ 程度）しか存在しないときには Na^+ 0.092 g atoms/L 以上で発育がおこったが，K^+ が0.046 g atoms/L 以上含まれるときには Na^+ 0.046 g atoms/L でも発育

Table 9. Response of sulfate-reducing bacteria strain SM 1 to Na^+. (Basal medium was prepared with the simplified artificial sea water from which NaCl was omitted.)

Concentrations of salts added to basal meidum (M)		Incubation time (hrs.)					
		16		36		75	
NaCl	NH_4Cl	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
0	0.460	10^3—10^4	0	10^2—10^3	0	1—10	0
0.023	0.437	10^3—10^4	0	10^2—10^3	0	0	0
0.115	0.345	10^5—10^6	0	10^7—10^8	0.007	10^9—10^{10}	0.096
0.230	0.230	10^7—10^8	0	10^8—10^9	0.023	10^8—10^9	0.211
0.345	0.115	10^6—10^7	0.005	10^9—10^{10}	0.108	10^9—10^{10}	0.233
0.437	0.023	10^7—10^8	0.005	10^9—10^{10}	0.117	10^9—10^{10}	0.244
0.460	0	10^7—10^8	0.006	10^9—10^{10}	0.098	10^8—10^9	0.235

Table 10. Response of sulfate-reducing bacteria strain SM 1 to Na^+ in the presence of K^+ in various concentrations. (Basal medium was prepared with the simplified artificial sea water from which Na^+ and K^+ were omitted. Na^+ and K^+ were added as chlorides. Cl^- which was reduced with the decrease of NaCl concentration was added to the medium as NH_4Cl in equimolar concentration.)

Concentration of Na^+ added (M)	Concentration of K^+ added (M)																									
	0.001							0.046							0.092											
	Incubation time (hrs.)																									
	30	48	72	117	192	240	552	30	48	72	117	192	240	552	30	48	72	117	192	240	552					
0.023	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−					
0.046	−	−	−	−	−	−	−	−	−	−	−	±	++		−	−	−	−	±	++						
0.092	−	++						−	++						±	++										
0.138	−	++						−	++						±	++										
0.184	−	++						++							+	++										
0.230	±	++						++							++											

Concentration of K^+ added (M)																										
0.138								0.184							0.230											
Incubation time (hrs.)																										
30	48	72	117	192	240	552		30	48	72	117	192	240	552		30	48	72	117	192	240	552				
−	−	−	−	−	−	−		−	−	−	−	−	−	−		−	−	−	−	−	−	−				
−	−	−	±	++				−	−	−	−	±	++			−	−	−	±	++						
±	++							±	++							±	++									
±	++							±	++							±	++									
±	++							±	++							±	++									
+	++							+	++							+	++									

が示された。しかし Na^+ 0.023 g atoms/L では K^+ がいかなる濃度に加えられても発育がみられなかった。そして発育速度はこれら両イオンの濃度の影響をともに受けたが，概して Na^+ 濃度によってより大きく支配されるようであって，Na^+ が比較的高濃度（0.184～0.230 g atoms/L）に存在するときには K^+ の至適濃度はむしろ低い値（0.046 g atoms/L 付近）にあるようにみえた。

上の結果から，この細菌の発育に対する Na^+ の必要量は共存する K^+ の濃度によってかなりの影響を受けるが，概して0.046～0.092 g atoms/L（通常の海水中における $\frac{1}{10}$～$\frac{1}{5}$ 程度）付近であると思われる。

（4）Na^+ の必要性に対する Ca^{++} または Mg^{++} の補償作用

つぎに，この細菌の Na^+ に対する要求を Ca^{++} または Mg^{++} によって一部補なうことができるか否かをみた。その方法は（3）におけると同様であって，培地中の Na^+ と Ca^{++} または Mg^{++} の g atoms の総和が常に海水中におけるものと等しくなるようにした。その結果は第 11 表および第 12 表に示す通りである。

Table 11. Response of sulfate-reducing bacteria strain SM 1 to Na^+ and Ca^{++}. (Basal medium was prepared with the simplified artificial sea water from which Na^+ was omitted. Na^+ and Ca^{++} were added as chlorides.)

Concentrations of Na^+ and Ca^{++} added (M)		Incubation time (hrs.)				
		15		40		88
Na^+	Ca^{++}	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Sulfides -S mg/ml
0	0.470	10^3—10^4	0	10^2—10^3	0	0
0.024	0.446	10^3—10^4	0	10^2—10^3	0	0
0.118	0.352	10^3—10^4	0	10^7—10^8	0	0.197
0.235	0.235	10^8—10^9	0.008	10^8—10^9	0.096	0.216
0.352	0.118	10^7—10^8	0.006	10^9—10^{10}	0.088	0.193
0.446	0.024	10^7—10^8	0.009	10^8—10^9	0.094	0.224
*0.460	*0.010	10^6—10^7	0.008	10^8—10^9	0.109	0.214
0.470	0	10^7—10^8	0.005	10^8—10^9	0.095	0.228

* Concentrations in natural sea water.

Table 12. Response of sulfate-reducing bacteria strain SM 1 to Na^+ and Mg^{++}. (Basal medium was prepared with the simplified artificial sea water from which Na^+ and Mg^{++} were omitted. Na^+ and Mg^{++} were added as chlorides.)

Concentrations of Na^+ and Mg^{++} added (M)		Incubation time (hrs.)				
		15		40		88
Na^+	Mg^{++}	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Sulfides -S mg/ml
0	0.512	10^3—10^4	0	10^3—10^4	0	0
0.026	0.486	10^3—10^4	0	10^3—10^4	0	0
0.128	0.384	10^7—10^8	0.003	10^7—10^8	0.117	0.254
0.256	0.256	10^7—10^8	0.001	10^8—10^9	0.120	0.241
0.384	0.128	10^8—10^9	0.003	10^9—10^{10}	0.122	0.239
*0.460	*0.052	10^8—10^9	0.008	10^9—10^{10}	0.121	0.248
0.486	0.026	10^7—10^8	0.004	10^8—10^9	0.120	0.233
0.512	0	10^4—10^5	0	10^3—10^4	0	0

* Concentrations in natural sea water.

すなわち，Ca^{++} が補なわれたときには，Na^{+} が0.118 g atoms/L 以上存在すると発育したが，その速度は Na^{+} 0.118 g atoms/L でかなりおくれたのを除いて 0.235～0.470 g atoms/L の範囲内ではほとんど差が認められなかった。また，Mg^{++} が補なわれたときには，Na^{+} 0.128～0.486 g atoms/L で発育し，その速度は Na^{+} 0.460，Mg^{++} 0.052 g atoms/L（通常の海水中における割合）でいく分大きいようであったが概して大差はみられなかった。

以上を第9表の結果と対比すると，この細菌による Na^{+} の要求はある程度 Ca^{++} または Mg^{++} によって満たされることが明らかである。すなわち，K^{+} の場合と同様に，Na^{+} を NH_4^{+} でおきかえた第9表における結果よりも Ca^{++} または Mg^{++} でおきかえた上の場合の方がかなりよい成績を示したことから，単なる滲透圧調節作用の他に少なくとも一部はイオンそのものによる補償的役割を果しているとみるべきであろう。

（5）滲透圧の要求に対する各種カチオンの効果

実験（3）および（4）の結果から，この細菌の発育に対する Na^{+} の必要性はおそらく K^{+}，Ca^{++} または Mg^{++} によって一部補償的に代用され得ると考えた。

上の実験は滲透圧をこの細菌の発育に最適である海水のレベルにそろえて行なったものであるが，つぎに Na^{+} は最低要求を満たす程度の低濃度とし，これに各種無機塩類または有機物をいろいろの濃度に加えて種々の滲透圧培地を調製し，この細菌の発育および硫化物生成作用に対する各種カチオンによる滲透圧の影

Table 13. Effects of the osmotic pressure of culture medium on the growth and the sulfide producing activity (strain S M 1). Desired osmotic pressure was obtained by adding NaCl, NH_4Cl, KCl, $CaCl_2$, $MgCl_2$ or glucose to the basal medium. Basal medium was prepared with the simplified artificial sea water containing NaCl in the concentration of 0.115 M.

Supplement		Incubation time (hrs.)					
		18		39		61.5	
		Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
Non (Basal medium only: NaCl 0.115 M)		10^4—10^5	0	10^6—10^7	0.002	10^9—10^{10}	0.083
NaCl	0.115 M	10^6—10^7	0.008	10^9—10^{10}	0.051	10^9—10^{10}	0.109
	0.230	10^7—10^8	0.013	10^9—10^{10}	0.064	10^8—10^9	0.150
	0.345	10^7—10^8	0.022	10^9—10^{10}	0.071	10^9—10^{10}	0.210
Glucose	0.230	10^4—10^5	0	10^6—10^7	0.002	10^8—10^9	0.047
	0.460	10^3—10^4	0	10^2—10^3	0	10^5—10^6	0.007
	0.690	10^3—10^4	0	10^3—10^4	0	10^6—10^7	0.005
NH_4Cl	0.115	10^3—10^4	0	10^7—10^8	0.005	10^9—10^{10}	0.045
	0.230	10^3—10^4	0	10^4—10^5	0	10^6—10^7	0.007
	0.345	10^3—10^4	0	10^3—10^4	0	10^7—10^8	0.011
KCl	0.115	10^7—10^8	0.008	10^9—10^{10}	0.053	10^8—10^9	0.115
	0.230	10^7—10^8	0.008	10^8—10^9	0.052	10^9—10^{10}	0.165
	0.345	10^7—10^8	trace	10^9—10^{10}	0.070	10^9—10^{10}	0.167
$CaCl_2$	0.115	10^7—10^8	trace	10^9—10^{10}	0.074	10^9—10^{10}	0.143
	0.230	10^6—10^7	trace	10^9—10^{10}	0.079	10^9—10^{10}	0.179
	0.345	10^3—10^4	0	10^8—10^9	0.056	10^9—10^{10}	0.080
$MgCl_2$	0.115	10^7—10^8	0.004	10^9—10^{10}	0.061	10^9—10^{10}	0.117
	0.230	10^7—10^8	0.022	10^9—10^{10}	0.067	10^9—10^{10}	0.163
	0.345	10^6—10^7	trace	10^9—10^{10}	0.078	10^9—10^{10}	0.268

響をみた。その結果は第13表に示す通りである。

すなわち，NaCl 0.115 M のみを含む基礎培地では，発育および硫化物生成作用がはなはだ緩慢であったが，KCl，$CaCl_2$ または $MgCl_2$ を加えて滲透圧を高めた培地ではこの速度が著しく大きくなり，同じモル濃度に NaCl を加えたものとほぼ等しいか，あるいはそれを上回る値を示した。そして，これらの速度の増大は概して滲透圧の増加と（海水における値付近までは）ほぼ比例したが，$CaCl_2$ の場合には最高濃度（0.345 M）においてはかえって低下した。また，これら促進作用は初期において Na^+ がその他のイオンよりもいく分大きいようであったが，大差はみられなかった。一方，ブドウ糖または NH_4Cl を加えて滲透圧を高めた培地では濃度とともに発育速度が小さくなり，明らかな阻害があらわれた。*

以上の結果は，不可欠カチオンがそれぞれこの細菌の最低要求量に存在する場合，発育および activity を主として支配するものは滲透圧であって，各カチオンの相対的比率は必らずしも海水中のそれを必要としないことを示すものといえよう。しかしカチオンの種類によってこの促進作用には多少の強弱が認められたが，さらにまた各イオン間には複雑な拮抗的関係が存在するかも知れない。なおこの場合，有機物は必らずしも有効ではないようである。

（6）Br^- および HCO_3^- の必要性

実験（2）において，完全人工海水から Br^- および HCO_3^- を欠いた塩類溶液で調製された培地でも十分な発育がみられたことから，この細菌の発育には Br^- および HCO_3^- はほとんど必要でないようにみえる。しかし，この場合の基礎培地中の有機物はアニオン除去処理が行なわれていなかったから，これからの微量の導入が考えられる。そこで，アニオン除去処理の行なわれた有機物を含む基礎培地に，KBr および $NaHCO_3$ を加えずに，または加えて培養しその影響をみた。

Table 14. Effects of Br^- and HCO_3^- on the growth and the sulfide-producing activity of sulfate-reducing bacteria strain SM 1. (Basal medium was prepared with the simplified artificial sea water.)

Treatment of basal medium with or without "Permutit A"	Added to basal medium (M)	At 30°C after 45 hrs.	
		Cells/ml	Sulfides -S mg/ml
Without	——	10^9—10^{10}	0.119
With	——	10^9—10^{10}	0.135
With	KBr(0.0008)	10^9—10^{10}	0.155
With	$NaHCO_3$(0.0023)	10^9—10^{10}	0.134
With	KBr(0.0008), $NaHCO_3$(0.0023)	10^9—10^{10}	0.133

結果は第14表に示す通り，有機物からアニオン除去処理を行なった場合にもこの処理を行なわなかった場合と同様の発育と activity を示し，またこれらの塩類を新たに加えてもその効果は認められなかった。したがって，この細菌の発育には Br^- および HCO_3^- はほとんど必要でないか，または極く微量にしか要求されず，少なくともこれを別に加える必要はないものと思われる。しかし，HCO_3^- については，一般に autotrophs のみならず heterotrophs の発育にとってもこれが微量の程度には不可欠であることが認められている。ことに上の場合に HCO_3^- 添加の影響がみられなかったのは，発育初期での観察が行なわれなかったこととともに空気中の CO_2 が培地（微アルカリ性）へ吸収され，おそらくこれが主として利用されたことによるのではなかろうか。

炭酸塩添加の影響をさらにくわしく検討するため，上と同様の HCO_3^- 欠除の基礎培地にいろいろの濃

* これらによる阻害が他の実験におけるより極めて顕著であったのは，Na^+ の存在する程度によって阻害の大きさが異なるためかも知れない。

Table 15. Effects of carbonates on the growth and the sulfide-producing activity of sulfate-reducing bacteria strain SM 1. (Basal medium was prepared with the simplified artificial sea water.)

Concentration of carbonates added (M)		Incubation time (hrs.)					
		23		37		59	
$NaHCO_3$	$CaCO_3$	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml
0	0	10^4—10^5	0	10^6—10^7	0.064	10^9—10^{10}	0.189
2×10^{-3}	0	10^4—10^5	0	10^6—10^7	0.061	10^9—10^{10}	0.144
5×10^{-3}	0	10^5—10^6	0	10^7—10^8	0.085	10^8—10^9	0.119
1×10^{-2}	0	10^4—10^5	0	10^6—10^7	0.074	10^9—10^{10}	0.158
2×10^{-2}	0	10^4—10^5	0	10^7—10^8	0.082	10^9—10^{10}	0.127
5×10^{-2}	0	10^3—10^4	0	10^2—10^3	0	1 —10	0
0	5×10^{-3}	10^5—10^6	0	10^6—10^7	0.079	10^9—10^{10}	0.204
0	1×10^{-2}	10^4—10^5	0	10^6—10^7	0.069	10^9—10^{10}	0.222
0	2×10^{-2}	10^4—10^5	0	10^6—10^7	0.075	10^9—10^{10}	0.224
0	5×10^{-2}	10^3—10^4	0	10^4—10^5	0.082	10^8—10^9	0.224

Incubation time (hrs.)			
106		208	
Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml
——	0.277	10^6—10^7	0.133
——	0.218	10^7—10^8	0.152
——	0.216	10^6—10^7	0.132
——	0.202	10^5—10^6	0.146
——	0.229	10^5—10^6	0.144
——	0	0	0
——	0.227	10^5—10^6	0.159
——	0.236	10^5—10^6	0.205
——	0.225	10^4—10^5	0.204
——	0.252	10^5—10^6	0.217

度の $NaHCO_3$ または $CaCO_3$ を加え，経時的に発育および硫化物生成量を測定した。その結果は第 15 表に示す通りであって，$NaHCO_3$ についてはほとんど添加の効果があらわれず，むしろ無添加の対照に比して硫化物の最大蓄積量が少ない傾向がみえた。一方，$CaCO_3$ についてはこの濃度範囲内ではほとんど大差がなかったが，無添加のものに比較すると硫化物の生成速度が概して大きかった。しかし $CaCO_3$ の最も多い 5×10^{-2} M では，初期の発育が他のいずれの培地でよりもいく分おくれた。

すなわち，炭酸塩が $NaHCO_3$ として加えられたときにはこの細菌の発育を促進する作用はほとんどないが，$CaCO_3$ として存在するときにはある範囲内ではある程度の促進作用があるのではなかろうか。後者における促進作用は，不溶性微粒子による固体表面の増加がこの細菌の発育に好都合な条件を与えたためかも知れない。

(7) Cl^- および SO_4^{--} の必要性

海水中におけるアニオンの主要部分を占める Cl^- および SO_4^{--} の必要性について調べた。すなわち，アニオン除去処理を行なった有機物の培地を，Cl^- または SO_4^{--} 欠除の塩類溶液で調製して，発育および

Table 16. Effects of Cl^- and SO_4^{--} on the growth and the sulfide-producing activity of sulfate-reducing bacteria strain S M1.

Modification of the simplified artificial sea water		Incubation time (hrs.)			
		20		41	
Omitted (M)	Added (M)	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
Non	Non	10^3—10^4	0	10^9—10^{10}	0.047
NaCl(0.460), KCl(0.010), $MgCl_2$(0.052)	Na_2SO_4(0.230), K_2SO_4(0.005), $MgSO_4$(0.052), Glucose(0.230)	10^3—10^4	0	10^3—10^4	0
NaCl(0.460), KCl(0.010), $MgCl_2$(0.052)	NaBr(0.460), KBr(0.010), $MgSO_4$(0.052)	10^3—10^4	0	10^2—10^3	0
*$(NH_4)_2SO_4$(0.028)	NH_4Cl(0.056)	10^3—10^4	0	10^3—10^4	0

Incubation time (hrs.)							
50		92		120		140	
Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
10^9—10^{10}	0.135	——	0.123	——	0.116	10^8—10^9	0.097
——	0	10^9—10^{10}	0.073	——	0.136	10^8—10^9	0.123
——	0	10^3—10^4	0	10^6—10^7	0.024	10^9—10^{10}	0.102
——	0	10^3—10^4	0	10^2—10^3	0	10^2—10^3	0

* With the medium in which requirement of SO_4^{--} was tested, $Fe(NH_4)_2(SO_4)_2$ contained in basal medium was replaced by the equimolar $FeCl_2$.

硫化物生成作用をみた。この場合，各カチオンの濃度はそれぞれ一定になるようにした。その結果は第16表に示す通り，Cl^- 塩をすべて相当する SO_4^{--} 塩または Br^- 塩でおきかえると，その速度ははなはだ小さかったが最後には十分な発育と相当量の硫化物生産がみられた。一方，SO_4^{--} 塩をそれぞれの Cl^- 塩でおきかえた場合には全く発育がおこらなかった。この結果，この細菌の発育にとって Cl^- はおそらく必須ではないが SO_4^{--} は必須不可欠のようにみえる。後者はこの細菌にとっては水素受容体として主要な代謝基質であるから，(少なくとも他の水素受容体がない場合には) 不可欠であるのは当然と思われる。

つぎに，Cl^- をいろいろの濃度に含む (Na^+ は等濃度に存在する) 培地で培養し，この細菌の発育および硫化物生成作用と Cl^- 濃度との関係をみた。その結果は第17表に示す通り，Cl^- を全く加えない場合にも発育がおこったがその速度および硫化物生産量は極めて小さく，その他の濃度範囲内でも発育速度および activity が Cl^- 濃度にある程度比例することがみられた。すなわち，Cl^- はこの細菌の発育に対してほとんど，または極めて僅かにしか要求されないが，ある範囲内では濃度に比例して発育促進作用をもつものと思われる。

Table 17. Effect of Cl^- concentration on the growth and the sulfide-producing activity of sulfate-reducing bacteria strain SM 1. (The composition of salts solution employed for the preparation of basal medium was: $(NH_4)_2SO_4$, 0.028 M; K_2SO_4, 0.005 M; $MgSO_4$, 0.052 M.)

Added to basal medium (M)			Incubation time (hrs.)					
			27		41		50	
NaCl	Na_2SO_4	Glucose	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
0	0.264	0.264	10^3—10^4	0	10^3—10^4	0	10^5—10^6	0
0.026	0.251	0.251	10^3—10^4	0	10^8—10^9	0.010	10^9—10^{10}	0.012
0.052	0.238	0.238	10^3—10^4	0	10^9—10^{10}	0.015	10^9—10^{10}	0.028
0.104	0.212	0.212	10^2—10^3	0	10^9—10^{10}	0.024	10^9—10^{10}	0.046
0.158	0.185	0.185	10^3—10^4	0	10^9—10^{10}	0.028	10^9—10^{10}	0.080
0.264	0.132	0.132	10^2—10^3	0	10^9—10^{10}	0.023	10^9—10^{10}	0.095
0.528	0	0	10^3—10^4	0	10^9—10^{10}	0.033	10^9—10^{10}	0.092

Incubation time (hrs.)					
66		92	98	140	
Cells/ml	Sulfides -S mg/ml	Sulfides -S mg/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
10^9—10^{10}	0.007	0.058	0.079	10^9—10^{10}	0.061
10^9—10^{10}	0.108	0.085	——	10^9—10^{10}	0.041
10^9—10^{10}	0.116	0.088	——	10^8—10^9	0.040
10^9—10^{10}	0.122	0.075	——	10^9—10^{10}	0.048
10^9—10^{10}	0.120	0.080	——	10^8—10^9	0.026
10^9—10^{10}	0.106	0.061	——	10^8—10^9	0.052
10^9—10^{10}	0.137	0.102	——	10^8—10^9	0.044

また，SO_4^{--} の必要性については他の水素受容体とともに現在くわしく検討中である。

(8) PO_4^{---} の影響

PO_4^{---} 欠除の基礎培地にいろいろの濃度の $(NH_4)_2HPO_4$ を加えて，この細菌の発育および硫化物生

Table 18. Effect of PO_4^{---} on the growth and the sulfide-producing activity of sulfate-reducing bacteria strain SM 1. (Basal medium was prepared with the simplified artificial sea water from which $(NH_4)_2HPO_4$ was omitted.)

Concentration of $(NH_4)_2HPO_4$ added to basal medium (g/L)	Incubation time (hrs.)									
	23		37		59		106	208		
	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml
0	10^4—10^5	0	10^4—10^5	0	10^7—10^8	0.082	0.209	10^5—10^6	0.123
0.015	10^4—10^5	0	10^6—10^7	0.096	10^8—10^9	0.191	0.189	10^4—10^5	0.121
0.030	10^4—10^5	0	10^6—10^7	0.098	10^9—10^{10}	0.210	0.193	10^5—10^6	0.139
0.075	10^4—10^5	0	10^5—10^6	0.071	10^9—10^{10}	0.194	0.194	10^5—10^6	0.124
0.150	10^3—10^4	0	10^5—10^6	0.049	10^8—10^9	0.147	0.204	10^4—10^5	0.142
0.300	10^4—10^5	0	10^5—10^6	0.066	10^9—10^{10}	0.143	0.185	10^5—10^6	0.129

成作用をみた。その結果は第18表に示す通りである。すなわち，PO_4^{---} を全く加えない培地でも十分な発育と硫化物生成作用が示されたが，その速度および activity は他のものにおけるよりもかなり小さかった。一方，PO_4^{---} を 0.015～0.300 g atoms/L 加えた培地では，いずれでもほとんど大差なく発育した。

このことから，PO_4^{---} はこの細菌の発育にとっておそらく不可欠であって，極めて低濃度においては発育はある程度これの濃度に比例するが，その必要量ははなはだ微量であろうと考えられる。

論　　議

一般に，微生物の発育および生理作用にとって K^+, Mg^{++}, Mn^{++}, Fe^{++}, PO_4^{---} あるいは SO_4^{--} など多くの無機要素が必要である[16]ことは周知の事実であるが，その詳細については余り明らかでない。その主な理由の一つは，培地に夾雑物として導入される微量の塩類を除くことが困難なためである。ことに，有機物を含む培地から塩類を完全に除くことは極めてむつかしく，確実な方法はまだ知られていない。

筆者は SHANKAR・BARD[13] ほか数氏がそれぞれ用いた方法を応用し，カチオン交換樹脂 "Permutit H—70" およびアニオン交換樹脂 "Permutit A" によって基礎培地からの有機物除去を試みたが，この方法によって真にイオンを除去することができたか否かは疑わしく*，また細心の注意を払ったにかかわらず試薬および器具などからの微量の夾雑物の混入をまぬがれ得なかったと思われる。しかし少なくとも，以上の実験においてその存在が発育に不可欠であるか，あるいは発育促進作用をもっていることが示されたものについてはおそらく疑いないところである。

すなわち，Na^+, K^+, Mg^{++} および SO_4^{--} はこの細菌の発育および硫化物生成にとって必須であり，その速度はある範囲内においてはこれらイオンの濃度に比例すると考えられる。また，PO_4^{---} については本実験結果ではその不可欠性が示されなかったが**，細菌の代謝系における燐酸塩の重要性から，また多くの細菌におけるこの塩の必要性から考えてこのものもおそらく必須であるとみられ，本実験においても低濃度付近では発育がこの濃度に比例することが示された。Cl^- も同様にその必須性は確認できなかったが，低濃度付近での growth response からみておそらく微量の程度に不可欠なのではなかろうか。また，HCO_3^- については，空気中からの CO_2 の溶解を防ぎ得なかったので上で得られた結果をそのまま認めることはできない。一般に細菌の無機塩要求性はその環境条件によって大きく支配されるが，ことに HCO_3^- については，この細菌が facultative autotrophs の一つとみなされ，H_2 の存在下では炭酸塩あるいは重炭酸塩を水素受容体として細胞原形質の合成に利用すると考えられる[12)17]ので，この意味からしてもこの細菌に対する炭酸塩の重要性は無視できない。しかし，本実験のように他に十分の有機炭素源ならびにエネルギー源が存在するときには，主として heterotrophic な発育を遂げるために炭酸塩は大量には要求されず，その発育促進作用もあらわれなかったとみるのが妥当ではなかろうか。この炭酸塩と硫酸塩還元細菌の発育との関係については，POSTGATE[18] が HCO_3^- または CO_2 によって発育が促進されたと報告している。

前報[1]において，この細菌の発育可能な NaCl 濃度範囲は 0.5～7.0 %程度であってその至適値は 3.0% 付近であることを明らかにしたが，本報における Na^+ の必要性についての結果と Cl^- に対する要求についての結果とを対照すると，この NaCl の必要性は Cl^- よりも Na^+ の必要性をより強く反映しているように思われる。しかし，この Na^+ そのものの必要限界量は，他のイオンにおけるよりはいく分大きいとはいえ，比較的少ないのであって，これが K^+, Ca^{++} または Mg^{++} によって一部補償的に代用されることがみられた上，一般にこれら Na^+ 以外の塩類によって滲透圧が高められるときにも，それが海水における値に近づくにしたがって発育および activity が増大することが示された。

---

* 事実，後報[11]のように微量の Fe^{++} が残されていることが判った。

** 基礎培地のペプトン中に相当量含まれていると思われる有機態燐化合物は，本報の除去処理では除かれないので，おそらくこれがこのような結果を与えたものと考えられる。

すなわち，この細菌の発育に対する個々のカチオンおよびアニオンの必要性は比較的低濃度で満たされ，これら不可欠イオンが最低要求濃度以上に存在する場合には，この細菌の発育および activity はこれらイオンの濃度比によるよりは，むしろ環境の滲透圧によって大きく支配されることが明らかである。したがって，この細菌の盛んな発育および activity の発現には必らずしも海水の塩分組成を必要とせず，他の塩類による場合であっても必要な滲透圧が保たれている環境下では（SO_4^{--} が十分存在するときには）この細菌が盛んな発育と硫化物生成作用を示すことがあり得ると考えられる。

摘　　要

海洋性硫酸塩還元細菌の発育および硫化物生成作用に対する各種カチオンおよびアニオンの必要性をしらべ，つぎの結果を得た。

1. この細菌の発育に対して Na^+, K^+, Mg^{++} および SO_4^{--} は必須不可欠であり，Cl^-, HCO_3^- および PO_4^{---} もおそらく不可欠のようであったが，Ca^{++} および Br^- の存在は（海水中における濃度付近では）ほとんどその影響が認められなかった。
2. 不可欠イオンのそれぞれの必要限界量は極めて微量であり，ある程度相互に補償的に代用できた。
3. この細菌の発育および activity を主として支配するものは（その他の条件が満たされたときには）環境の滲透圧であって，イオンの相対的濃度比は必らずしも海水中のそれを必要としなかった。

本研究にあたり，ご指導いただいた京都大学農学部木俣正夫教授，およびご指導ならびにご校閲いただいた京都大学食糧科学研究所門田　元教授に厚くお礼申し上げる。また，イオン交換樹脂の入手にご便宜をいただいた東京大学大学院富山哲雄氏に深謝する。

文　　献

1) 畑　　幸彦：1960. 本報告，**9**，329—345.
2) 木俣正夫・門田　元・畑　幸彦・田島卓明：1955. 日本水産学会誌，**21**，113—118.
3) BUTLIN, K. R., M. E. ADAMS and M. THOMAS：1949. *J. gen. Microbiol.*, **3**, 46—59.
4) POSTGATE, J. R.：1956. *J. gen. Microbiol.*, **15**, 186—193.
5) MILLER, L. P.：1950. *Contrib. Boyce Thompson Inst.*, **16**, 74—83.
　————：1950. *Ibid.*, **16**, 85—89.
6) UPDEGRAFF, D. M. and G. B. WREN：1952. *Bact. Proc.*, p. 136.
7) BAAS BECKING, L. G. M. and E. J. F. WOOD：1955. *Proc. Kon. Ned. Ak. v. Wet. Amsterdam*, **58**, 160—181.
8) 鈴木新一・志賀一一：1953. 中国農試報告，A (2)，73—90.
9) KOYAMA, T. and K. SUGAWARA：1953. *J. Earth Sci.*, Nagoya Univ., **1**, 24—34.
10) MACLEOD, R. A. and E. ONOFREY：1956. *J. Bact.*, **71**, 661—667.
　————————：1957. *Cand. J. Microbiol.*, **3**, 753—759.
11) 畑　　幸彦：1960. 本報告，**9**，3 63—375.
12) 木俣正夫・門田　元・畑　幸彦：1955. 日本水産学会誌，**21**，229—234.
　————————：1955. ————————，**21**，235—239.
13) SHANKAR, K. and R. C. BARD：1952. *J. Bact.*, **63**, 279—290.
14) LYMAN, J. and R. H. FLEMING：1940. *J. Marine Research*, **3**, 134—146.
15) 富山哲夫・神崎嘉瑞夫：1951. 日本水産学会誌，**17**，115—121.
16) SNELL, E. E.：1951. "Bacterial Physiology (Ed. by WERKMAN, C. H. and P. W. WILSON)", Academic Press, New York. pp. 219—220.
　KNIGHT, S. G.：1951. *Ibid*, pp. 500—516.
17) SISLER, F. D. and C. E. ZOBELL：1951. *J. Bact.*, **62**, 117—127.
18) POSTGATE, J. R.：1951. *J. gen. Microbiol.*, **5**, 714—724.

海洋性硫酸塩還元細菌におよぼす重金属塩類の影響※

畑　　幸　彦

Influence of Heavy Metals upon the Growth and the Activity of Marine Sulfate-Reducing Bacteria※

By

Yoshihiko HATA

The author has previously shown, with the other workers in the research group of Kyōto University, that Fe^{++} was essential for the growth of marine sulfate-reducing bacteria, and that the development of sulfides by these organisms was stimulated by Fe^{++} and partly or completely inhibited by Mn^{++}, Zn^{++}, Co^{++} and Cu^{++}.

The present paper embodies the more detailed data on the influence of heavy metals upon the growth and the sulfate-reducing activity of these bacteria.

Marine sulfate-reducing bacteria strain SM 1 was used throughout this work. Heavy metals originally contained in peptone and lactic acid employed were removed by use of the 8-hydroxyquinoline treatment.

The results obtained are shown in Tables 1—10, and may be summarized as follows :

1) Although in very low concentration (about 10^{-8}—10^{-7} g atoms per L) Fe^{++} was essentially required for the growth of these organisms. In the medium containing peptone and lactic acid which were not treated with 8-hydroxyquinoline, good growth was obtained without the addition of Fe^{++}.

2) The growth and the sulfate-reducing activity of these bacteria were markedly stimulated by the addition of Fe^{++} within certain limits. Fe^{+++}, iron powder or insoluble iron salts also exhibited stimulatory effect. This effect is probably due to the formation of Fe^{++} from Fe^{+++} or iron metal in the culture.

3) When Bi, Co, Cr, Mn, Pb and Sb were present in the culture media sulfides

※ 水産講習所研究業績　第305号,　1960年2月11日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 305.
Received　Feb. 11, 1960.

were accumulated in higher concentration than in the absence of these metals, although the initial growth of the bacteria was considerable retarded as compared with the latter case. These results may suggest that the above metals acted not only as inhibitors of the bacterial growth, but also as precipitators of free H_2S produced. As has been mentioned previously, the removal of free H_2S by precipitation from the media has a favorable effect upon the sulfate-reducing activity of these bacteria.

4) The growth of these organisms were inhibited partly by Ni and Zn, and completely by Cd and Cu.

5) The remarkable antagonistic action of Mn^{++} and Cd^{++} upon the stimulatory effect of Fe^{++} was observed in the growth of these organisms. The other metals also showed this action upon Fe^{++} to some extent.

海洋性硫酸塩還元細菌の発育ならびに activity に対する塩分濃度の影響，および海水の塩分を構成する主なカチオンならびにアニオンの必要性などについては既報[1)2)]において明らかにした。また，この細菌の発育に Fe^{++} が必須不可欠であること[3)]および多量の Fe^{++} が存在すると遊離硫化水素による発育阻害が除かれること[4)]について述べ，Mn^{++}, Zn^{++}, Co^{++} および Cu^{++} の阻害的影響についても予備的に報告した。[3)]

本報では，これらを拡張して，Fe^{++}, Mn^{++}, Zn^{++} をはじめ比較的原子量の大きい種々の金属のイオンおよびこれら金属の不溶性塩類がこの細菌の発育ならびに activity にどのような影響を与えるかについて更にくわしく検討した結果を述べる。

実 験 方 法

1. 供試菌株：海洋性硫酸塩還元細菌の代表的菌株である SM 1 を用いた。

Table 1. Composition of basal medium.

Peptone	2.0 g	
Lactic acid	2.5	
$(NH_4)_2HPO_4$	0.15	
L-Ascorbic acid	0.2	
NaCl	23.5	Artificial sea water
$MgCl_2 \cdot 6H_2O$	10.6	
KCl	0.7	
Na_2SO_4	3.9	
$CaCl_2 \cdot 2H_2O$	1.5	
Distilled water	1,000 ml	
pH 7.5		

2. 基礎培地の調製：既報[2)]における実験では，第1表の基礎培地中のペプトンおよび乳酸をイオン交換樹脂 "Permutit H—70" (H—form) および "Permutit A" (OH—form) のカラムを通してイオン欠除としたが，予備実験において，この方法では別に Fe^{++} を加えなくても十分な発育が得られたのに対して，下に述べる方法にしたがい 8-hydroxyquinoline (oxine) で処理した場合にはこれに Fe^{++} を加えないと全

く発育しなかった。このことから，少なくとも Fe^{++} の除去については "Permutit" 処理では不十分であるが oxine 処理によれば十分であることが明らかになったので，本報ではすべて，WARING・WERKMAN[5]の方法に準じてつぎのように処理した。

すなわち，基礎培地における2倍濃度のペプトン・乳酸溶液（pH 7.0）500 ml をあらかじめ 15 ポンド 20 分間オートクレーブし，これに 8-hydroxyquinoline (oxine) の 1% クロロフォルム溶液 30 ml を加え分液濾斗中で5分間はげしく振盪する。このとき微量に混在する Fe^{++} などが oxine と反応して黒褐色に着色する。これを静置し oxine 溶液を下層に集めて捨てる。これを数回くり返して着色がおこらなくなれば，クロロフォルムのみを加えて同様の方法で数回洗滌し oxine を除く。このものを 80°C の湯浴上で約 30 分間はげしく通気してクロロフォルムを除く。以上の全操作を2回くり返す。

これに他の必要塩類を加え pH を修正して後，加熱による塩類の変化をできるだけ避けるためコッホ釜で 30 分間蒸気滅菌する。滅菌後，無菌的操作によって pH を再修正する。

3. 硫化物の定量：全硫化物の定量は富山・神崎の方法[6]によったが，"free H_2S" はこの方法において塩酸酸性とせずそのまま（微アルカリ性）で水蒸気蒸溜した（したがって厳密な意味での free H_2S ではない）。また，Fe^{++} など易還元性金属イオンを多量に含むサンプルについては，これらイオンによる H_2S の酸化のための誤差を防ぐ目的で，富山・小島の方法[7]にしたがって粉末 Mg を加え H_2 の発生下で水蒸気蒸溜した。

4. 硫酸イオンの定量：塩化バリウム溶液を加えて硫酸バリウムとする重量分析法[8]によった。

その他の方法は，すべて既報[2]で述べたと全く同様である。

実 験 結 果

（1）Fe^{++} の必要性ならびにその濃度の影響

この細菌の発育および硫化物生成作用に対する Fe^{++} の影響については既報[3][4]において予備的に明らかにしたが，つぎの実験でさらにくわしく追究した。

すなわち，第1表の組成から $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ を除いた基礎培地を，oxine で処理しまたは処理しないペプトン，乳酸で調製し，これらに $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ を加えないで，あるいは加えてこの細菌を培養した。この場合，対照のため人工海水のかわりに天然海水で調製した培地についても行なった。その結果は第2表に示す通り，oxine で処理しなかった有機物を含む培地では Fe^{++} を加えなく

Table 2. Effect of Fe^{++} on the growth and the activity of sulfate-reducing bacteria strain SM 1 in the media prepared with natural or artificial sea water containing peptone and lactic acid which were preliminarily treated with 8-hydroxyquinoline (oxine) or not.

With or without oxine treatment	Sea water base	$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ added (g/L)	Incubation time (hrs.)							
			24		47		64		112	
			Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Cells/ml	Sulfides -S mg/ml	Sulfides -S mg/ml	
Without	Artificial	0.2	10^8—10^9	0.009	10^9—10^{10}	0.202	10^9—10^{10}	0.308	0.139	
Without	Artificial	0	10^2—10^3	0	10^9—10^{10}	0.214	10^9—10^{10}	0.192	0.171	
With	Artificial	0.2	10^9—10^{10}	0.035	10^9—10^{10}	0.348	10^9—10^{10}	0.208	0.141	
With	Artificial	0	10^2—10^3	0	10^2—10^3	0	10 —10^2	0	0	
With	Natural	0.2	10^8—10^9	0.029	10^9—10^{10}	0.316	10^9—10^{10}	0.288	0.207	
With	Natural	0	10^2—10^3	0	10^2—10^3	0	10^2—10^3	0	0	

ても十分発育したが，この場合の硫化物最高蓄積量は Fe^{++} を加えた培地にくらべるとかなり少なかった。一方，oxine の処理を行なった有機物の培地では，人工海水の場合でもあるいは天然海水の場合でも Fe^{++} を加えないと発育がおこらず，これを加えるとさかんな発育と硫化物の生成が示され両者間に大差がみられなかった。

以上の結果から，この細菌の発育には Fe^{++} が必須不可欠であるが，未処理のペプトンまたは乳酸中にはこの要求を満たすのに十分な程度の Fe^{++} が存在すると考えられる。一方，天然海水中にはこの要求を満たす程度の Fe^{++} を含んでいないようにみえる。また，これら有機物は oxine 処理によって Fe^{++} が除かれること以外にはこの細菌の発育に対して全く影響をおよぼさないことが明らかになったので，以下の実験では第1表の組成中の有機物をこの処理によってイオン欠除としたものを基礎培地とすることにした。

つぎに，Fe^{++} とこの細菌の発育および硫酸塩還元作用との関係をさらにくわしく調べるため，いろいろの濃度に $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ を加えて培養し，発育，硫化物蓄積量および硫酸塩還元量を経時的に測定した。硫酸塩還元量は残存する硫酸イオンの量から算出した。

その結果は第3表に示すように，Fe^{++} 10^{-7}～10^{-2}g atoms/L の範囲内で発育したが，10^{-8}g atoms/L 以下および 10^{-1}g atoms/L では全く発育がみられなかった。そして発育速度，硫化物最高蓄積量および硫酸塩還元総量は発育可能範囲内ではいずれも Fe^{++} の濃度とほぼ比例し，また長時間培養後の死滅期における生菌数は Fe^{++} 濃度の高いものにおけるほど多かった。Fe^{++} によるこれら促進作用は，既報[4]において述べたように遊離硫化水素が Fe^{++} と反応して不溶性硫化鉄となるためこれによる発育阻害が除かれることが主な原因であると考えられるが，"free H_2S" が同程度に存在するときにも一般に Fe^{++} が高濃度であるほど促進作用が著しかったことから，その一部は Fe^{++} 自体のせいに帰せられよう。また，Fe^{++} 10^{-1}g atoms/L では全く発育しなかったが，これと当量の $FeCl_2$ または $(NH_4)_2SO_4$ によっても同様の阻害がみられたことから，これは高濃度の Fe^{++} によるためか，あるいは高濃度の NH_4^+，SO_4^{--} または高滲透圧によるためかは明らかでない。

Table 3. Response of sulfate-reducing bacteria strain S M 1 to Fe^{++}.

Added to basal medium (M)			Incubation time (hrs.)							
			21		40			68		
$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$	$FeCl_2$	$(NH_4)_2SO_4$	Cells/ml	"Free H_2S" –S; Insoluble sulfides–S mg/ml	Cells/ml	"Free H_2S" –S; Insoluble sulfides–S mg/ml	Reduced* sulfate–S mg/ml	Cells/ml	"Free H_2S" –S; Insoluble sulfides–S mg/ml	
0	0	2×10^{-2}	10^2—10^3	0	10 —10^2	0	0	10 —10^2	0	
10^{-9}	0	2×10^{-2}	10 —10^2	0	10^2—10^3	0	0	10 —10^2	0	
10^{-8}	0	2×10^{-2}	10^2—10^3	0	10 —10^2	0	0	10 —10^2	0	
10^{-7}	0	2×10^{-2}	10^2—10^3	0	10^8—10^9	0	0	10^9—10^{10}	0.024 ; 0	
10^{-6}	0	2×10^{-2}	10^7—10^8	0	10^9—10^{10}	0.087 ; 0	0 094	10^9—10^{10}	0.144 ; 0.013	
10^{-5}	0	2×10^{-2}	10^7—10^8	0	10^9—10^{10}	0.212 ; 0.011	0.224	10^9—10^{10}	0.265 ; 0.017	
10^{-4}	0	2×10^{-2}	10^8—10^9	0.020 ; 0.005	10^9—10^{10}	0.232 ; 0.018	0.280	10^9—10^{10}	0.256 ; 0.016	
10^{-3}	0	2×10^{-2}	10^9—10^{10}	0.013 ; 0.042	10^9—10^{10}	0.160 ; 0.068	0.235	10^9—10^{10}	0.265 ; 0.071	
10^{-2}	0	0	10^8—10^9	0.012 ; 0.009	10^9—10^{10}	0.026 ; 0.182	0.215	10^9—10^{10}	0.053 ; 0.297	
10^{-1}	0	0	10 —10^2	0	10^2—10^3	0	0	10 —10^2	0	
10^{-3}	0	2×10^{-1}	10^2—10^3	0	10 —10^2	0	0	1 —10	0	
0	10^{-1}	0	10^2—10^3	0	10^2—10^3	0	0	10 —10^2	0	

Incubation time (hrs.)								
92			164			236		
Cells/ml	"Free H_2S" –S; Insoluble sulfides–S mg/ml	Reduced sulfate–S mg/ml	Cells/ml	"Free H_2S" –S; Insoluble sulfides–S mg/ml	Reduced sulfate–S mg/ml	Cells/ml	"Free H_2S" –S; Insoluble sulfides–S mg/ml	Reduced sulfate–S mg/ml
$10-10^2$	0	0	$1-10$	0	0	0	0	0
$1-10$	0	0	$1-10$	0	0	0	0	0
$1-10$	0	0	$1-10$	0	0	0	0	0
10^8-10^9	——	——	10^5-10^6	0.022 ; 0.012	0.057	10^3-10^4	0.029 ; 0.010	0.065
10^9-10^{10}	0.131 ; 0.007	0.325	10^6-10^7	0.012 ; 0.072	0.354	10^3-10^4	0.064 ; 0.011	0.374
10^9-10^{10}	0.228 ; 0.014	0.370	10^5-10^6	0.108 ; 0.014	0.479	10^3-10^4	0.013 ; 0.072	0.509
10^9-10^{10}	0.188 ; 0.021	0.402	10^5-10^6	0.060 ; 0.016	0.526	10^5-10^6	0.072 ; 0.020	0.554
10^9-10^{10}	0.178 ; 0.065	0.477	10^7-10^8	0.095 ; 0.011	0.600	10^5-10^6	0.079 ; 0.017	0.638
10^9-10^{10}	0.071 ; 0.882	1.228	10^9-10^{10}	0.207 ; 0.901	1.248	10^9-10^{10}	0.017 ; 0.214	1.281
$1-10$	0	0	0	0	0	0	0	0
$1-10$	0	0	0	0	0	0	0	0
$10-10^2$	0	0	$1-10$	0	0	0	0	0

* Calculated from the amount of SO_4^{--} remained in the culture medium.

(2) Fe^{++} が存在しない場合における他の金属イオンの影響

上の実験で，この細菌の発育には Fe^{++} が不可欠であることが示されたが，これの必要性を他の金属イオンで代用できるか否かをみるため，第4表に示すいろいろの金属塩類を 10^{-3} M の濃度に加えて培養した。

Table 4. Response of sulfate-reducing bacteria strain S M 1 to Bi^{+++}, Cd^{++}, Co^{++}, Cr^{+++}, Cu^{++}, Fe^{++}, Mn^{++}, Ni^{++}, Pb^{++}, Sb^{+++} or Zn^{++} in the absence of Fe^{++}. (These metalic ions were added in the concentration of 10^{-3}g atoms per L.)

Salt added	Incubation time (hrs.)				
	88		182		
	Cells/ml	Sulfides–S mg/ml	Cells/ml	Sulfides–S mg/ml	Reduced sulfate–S mg/ml
Non	no growth			no growth	
$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$	10^9-10^{10}	0.228	10^9-10^{10}	0.112	0.514
* $BiCl_3$	10^8-10^9	0.081	10^8-10^9	0.066	0.283
$CdSO_4 \cdot 2H_2O$	no growth			no growth	
$CoSO_4 \cdot 7H_2O$	no growth			no growth	
$CrK(SO_4)_2 \cdot 12H_2O$	no growth			no growth	
$CuSO_4 \cdot 5H_2O$	no growth			no growth	
$FeNH_4(SO_4)_2 \cdot 12H_2O$	10^9-10^{10}	0.236	10^8-10^9	0.166	0.640
$MnSO_4 \cdot 7H_2O$	no growth			no growth	
$NiSO_4 \cdot 7H_2O$	no growth			no growth	
$PbCl_2$	no growth			no growth	
$SbCl_3$	no growth			no growth	
$ZnSO_4 \cdot 7H_2O$	no growth			no growth	

* Sulfide formed was not completly detected by means of the analytical method employed.

その結果，Fe^{++} 以外では Bi^{+++} および Fe^{+++} のみにおいては十分な発育と activity が示されたが，その他のイオンでは全く発育がおこらなかった。しかし，Bi^{+++} および Fe^{+++} が真に Fe^{++} の代用となり得たのか否かははなはだ疑問である。すなわち，これらの塩類には微量の Fe^{++} が夾雑物として混在する可能性が高いので，おそらく試薬が不純であったためと考えるのが妥当であろう。ことに Fe^{+++} については，培地の初期 Eh が低いため部分的な Fe^{++} への還元がおこり，発育および硫化物生成にともなって一層この傾向がつよめられ Fe^{++} と同様の著しい促進作用があらわれたものと思われる。

結局，おそらく Fe^{++} の必要性は他のイオンによっては代用され得ないと考えられる。

(3) Fe^{++} が微量に存在する場合における他の金属イオンの影響

上に述べたように，比較的高濃度の Fe^{++} による発育ならびに硫酸塩還元に対する促進作用の主な原因は，free H_2S を不溶性 FeS として沈澱させるためこれによる阻害が除かれることにあると考えられるが，このことから，一般に H_2S と反応して不溶性硫化物をつくるその他の金属イオンにも同様の促進作用があるかも知れないと思われる。この点をたしかめるため，Fe^{++} がこの細菌の発育をささえ得る程度の微量に存在するときにおける，これら金属イオンの影響をしらべた。その結果は第5および6表に示す通りである。

Table 5. Effects of Bi^{+++}, Cd^{++}, Co^{++}, Cr^{+++}, Fe^{+++}, Mn^{++}, Ni^{++}, Pb^{++}, Sb^{+++} or Zn^{++} in various concentrations on the growth and the activity of sulfate-reducing bacteria strain SM 1 in the presence of Fe^{++} in the concentration of 10^{-6}g atoms per L. (Fe^{++} was provided as $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$.)

Salt added (M)		Incubation time (hrs.)			
		57		157	
		Cells/ml	Sulfides-S mg/ml	Cells/ml	Sulfides-S mg/ml
Non (Basal medium only)		10^8—10^9	0.114	10^7—10^8	0.079
$(NH_4)_2SO_4$	10^{-2}	10^7—10^8	0.107	10^7—10^8	0.090
$Fe(NH_4)_2(SO_4)_2$	10^{-4}	10^7—10^8	0.101	10^8—10^9	0.205
	10^{-3}	10^9—10^{10}	0.288	10^9—10^{10}	0.264
	10^{-2}	10^9—10^{10}	0.374	10^8—10^9	0.331
* $BiCl_3$	10^{-4}	10^8—10^9	0.155	10^8—10^9	0.094
	10^{-3}	10^7—10^8	0.245	10^8—10^9	0.119
	10^{-2}	10^8—10^9	0.228	10^7—10^8	0.185
$CdSO_4 \cdot 2H_2O$	10^{-4}	10^2—10^3	0	0	0
	10^{-3}	1 —10	0	0	0
	10^{-2}	1 —10	0	0	0
$CoSO_4 \cdot 7H_2O$	10^{-4}	10^8—10^9	0.146	10^8—10^9	0.148
	10^{-3}	0	0	0	0
	10^{-2}	0	0	0	0
$CrK(SO_4)_2 \cdot 12H_2O$	10^{-4}	10^7—10^8	0.132	10^7—10^8	0.064
	10^{-3}	10^4—10^5	0	10^7—10^8	0.055
	10^{-2}	10^3—10^4	0	0	0
$CuSO_4 \cdot 5H_2O$	10^{-4}	0	0	0	0
	10^{-3}	0	0	0	0
	10^{-2}	0	0	0	0
$Fe\ NH_4(SO_4)_2 \cdot 12H_2O$	10^{-4}	10^8—17^9	0.154	10^9—10^{10}	0.192
	10^{-3}	10^8—10^9	0.242	10^8—10^9	0.228
	10^{-2}	10^9—10^{10}	0.409	10^9—10^{10}	0.320

$MnSO_4 \cdot 7H_2O$	10^{-4}	10^9—10^{10}	0.017	10^7—10^8	0.098
	10^{-3}	10^8—10^9	0.123	10^7—10^8	0.094
	10^{-2}	10^4—10^5	0	0	0
* $NiSO_4 \cdot 7H_2O$	10^{-4}	10^4—10^5	0	10^7—10^8	0.114
	10^{-3}	10^3—10^4	0	0	0
	10^{-2}	10^3—10^4	0	0	0
$PbCl_2$	10^{-4}	10^4—10^5	0	10^6—10^7	0.053
	10^{-3}	0	0	0	0
	10^{-2}	0	0	0	0
$SbCl_3$	10^{-4}	10^3—10^4	0	0	0
	10^{-3}	10^4—10^5	0	0	0
	10^{-2}	10^3—10^4	0	0	0
$ZnSO_4 \cdot 7H_2O$	10^{-4}	0	0	0	0
	10^{-3}	0	0	0	0
	10^{-2}	0	0	0	0

* Sulfides formed were not completely detected by means of the analytical method employed.

Table 6. Effects of various ions on the growth and the activity of sulfate-reducing bacteria strain SM 1 in the presence of Fe# in the concentration of 10^{-4}g atoms per L. (Basal medium contained $Fe(NH_4)_2(SO_4)_2$ in the concentration of 10^{-4}M.)

Salt added (M)		Incubation time (hrs.)								
		30		43		110		182		
		Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Reduced Sulfate –S mg/ml
Non (Basal medium only)		10^7—10^8	0.129	10^9—10^{10}	0.302	——	0.178	10^6—10^7	0.085	0.380
$(NH_4)_2SO_4$	10^{-2}	10^6—10^7	0.093	10^9—10^{10}	0.223	——	0.152	10^7—10^8	0.109	0.357
$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$	10^{-4}	10^7—10^8	0.108	10^9—10^{10}	0.295	——	0.166	10^6—10^7	0.179	0.281
	10^{-3}	10^7—10^8	0.154	10^9—10^{10}	0.318	——	0.197	10^8—10^9	0.201	0.384
	10^{-2}	10^6—10^7	0.132	10^9—10^{10}	0.314	——	0.346	10^9—10^{10}	0.329	0.584
*$BiCl_3$	10^{-4}	10^6—10^7	0.119	10^9—10^{10}	0.320	——	0.152	10^7—10^8	0.058	——
	10^{-3}	10^5—10^6	0.077	10^8—10^9	0.229	——	0.189	10^7—10^8	0.096	0.406
	10^{-2}	10^5—10^6	0.102	10^9—10^{10}	0.330	——	0.254	10^9—10^{10}	0.067	0.366
$CdSO_4 \cdot 2H_2O$	10^{-4}	10^2—10^3	0	10^2—10^3	0	——	0	0	0	0
	10^{-3}	10^3—10^4	0	10 —10^2	0	——	0	0	0	0
	10^{-2}	10^2—10^3	0	10 —10^2	0	——	0	0	0	0
$CoSO_4 \cdot 7H_2O$	10^{-4}	10^6—10^7	0.074	10^9—10^{10}	0.282	——	0.246	10^7—10^8	0.033	0.401
	10^{-3}	10^4—10^5	0.022	10^9—10^{10}	0.188	——	0.164	10^7—10^8	0.041	0.480
	10^{-2}	10^3—10^4	0	10^2—10^3	0	——	0	0	0	0
$CrK(SO_4)_2 \cdot 12H_2O$	10^{-4}	10^7—10^8	0.090	10^9—10^{10}	0.270	——	0.202	10^8—10^9	0.089	0.377
	10^{-3}	10^2—10^3	0	10^4—10^5	0	10^8—10^9	0.224	10^8—10^9	0.140	0.362
	10^{-2}	10^3—10^4	0	10^3—10^4	0	10^9—10^{10}	0.252	10^9—10^{10}	0.187	0.514
$CuSO_4 \cdot 5H_2O$	10^{-4}	0	0	0	0	——	0	0	0	0
	10^{-3}	0	0	0	0	——	0	0	0	0
	10^{-2}	0	0	0	0	——	0	0	0	0
$FeNH_4(SO_4)_2 \cdot 12H_2O$	10^{-4}	10^6—10^7	0.109	10^9—10^{10}	0.280	——	0.174	10^8—10^9	0.140	0.385
	10^{-3}	10^7—10^8	0.122	10^9—10^{10}	0.275	——	0.240	10^7—10^8	0.206	0.392
	10^{-2}	10^6—10^7	0.155	10^9—10^{10}	0.381	——	0.340	10^9—10^{10}	0.272	0.700

$MnSO_4 \cdot 7H_2O$	10^{-4}	10^6—10^7	0.106	10^9—10^{10}	0.301	——	0.180	10^4—10^5	0.086	0.462
	10^{-3}	10^6—10^7	0.132	10^9—10^{10}	0.296	——	0.188	10^6—10^7	0.087	0.414
	10^{-2}	10^3—10^4	0.084	10^4—10^5	0	10^4—10^5	0.209	10^8—10^9	0.246	0.396
*$NiSO_4 \cdot 7H_2O$	10^{-4}	10^4—10^5	0.088	10^9—10^{10}	0.280	——	0.148	10^7—10^8	0.032	0.401
	10^{-3}	10^5—10^6	0.113	10^9—10^{10}	0.276	——	0.189	10^8—10^9	0.047	0.300
	10^{-2}	10^3—10^4	0	10^2—10^3	0	——	0	0	0	0
$PbCl_2$	10^{-4}	10^3—10^4	0	10^3—10^4	0	10^9—10^{10}	0.230	10^7—10^8	0.157	0.383
	10^{-3}	10^3—10^4	0	10^3—10^4	0	10^8—10^9	0.252	10^7—10^8	0.193	0.372
	10^{-2}	10^2—10^3	0	0	0	——	0	0	0	0
$SbCl_3$	10^{-4}	10^5—10^6	0.124	10^9—10^{10}	0.348	——	0.187	10^7—10^8	0.091	0.470
	10^{-3}	10^2—10^3	0	10 —10^2	0	——	0	1 —10	0	0
	10^{-2}	10^3—10^4	0	10^2—10^3	0	——	0	0	0	0
$ZnSO_4 \cdot 7H_2O$	10^{-4}	10^6—10^7	0.067	10^9—10^{10}	0.298	——	0.183	10^6—10^7	0.070	0.440
	10^{-3}	10^2—10^3	0	1 —10	0	——	0	0	0	0
	10^{-2}	10^2—10^3	0	10 —10^2	0	——	0	0	0	0

* Sulfides formed were not completely detected by means of the analytical method employed.

すなわち，Fe^{++} が 10^{-6}g atoms/L 存在するときには，Bi^{+++} 10^{-4}～10^{-2}g atoms/L，Co^{++} 10^{-4}g atoms/L および Fe^{+++} 10^{-4}～10^{-2}g atoms/L において明らかな促進作用が認められたが，これらの濃度以上においては，あるいはその他の金属イオンの場合にはかえって著しい阻害作用が示された。また，Fe^{++} が 10^{-4}g atoms/L 共存するときには，Fe^{+++} において最初から著しい促進作用が認められ，Bi^{+++}，Co^{++}，Cr^{+++}，Mn^{++}，Pb^{++} および Sb^{+++} では終期における硫化物蓄積量および硫酸塩還元量が各濃度に応じて多少とも増大する傾向が示された。Ni^{++} および Zn^{++} ではこれらの最終値には大差がなかったが概して阻害的傾向がつよく，Cd^{++} および Cu^{++} では全く発育がみられなかった。そして，上述のような終期において促進作用が示されたものについても初期には明らかな阻害作用があらわれ，この傾向は一般に高濃度におけるほど著しかった。一方，$(NH_4)_2SO_4$ を 10^{-2} M 加えた培地では阻害がそれほど顕著でなかったことから，これらの阻害の原因は高濃度の SO_4^{--} あるいは高滲透圧のみには帰せられない。

すなわち，これらの金属イオンの多くは本来この細菌の発育に対して多少とも阻害作用をもつものであるが，一方生成された H_2S と反応してこれを不活性化されるため，終期における発育および硫酸塩還元作用が H_2S に阻害されることなく進むものとみられる。また，生産された H_2S が不溶性硫化物として固定されるため，逸散または酸化による消失が防がれて全硫化物の最高蓄積量が高くあらわれると考えられる。

しかし，以上の実験において Fe^{++} が比較的高濃度に共存する場合の方がこれら金属イオンによる阻害的傾向がいちじるしく弱められたことは，これらのイオンと Fe^{++} との間の拮抗的関係を示すものである。そこで，つぎにこれらの代表的な場合として Fe^{++} と Mn^{++} との間の拮抗作用について実験した。

(4) Fe^{++} の促進効果に対する Mn^{++} の拮抗作用

基礎培地に Fe^{++} および Mn^{++} をいろいろの濃度に加えて培養し，これらの影響をみた。その結果は第7表に示す通り，Fe^{++} が 10^{-6}g atoms/L 存在するときには Mn^{++} 10^{-3}g atoms/L 以上において，また Fe^{++} 10^{-3}g atoms/L のときには Mn^{++} 10^{-2}g atoms/L においてそれぞれ発育および activity が明らかに阻害されたが，Fe^{++} が 10^{-2}g atoms/L 存在する場合には Mn^{++} 10^{-2}g atoms/L で微弱な阻害がみられたに過ぎずそれ以下の Mn^{++} 濃度では阻害がおこらなかった。そして，これら阻害の大きさは一般に Mn^{++} の濃度に比例した。

すなわち，Mn^{++} はこの細菌の発育および activity に対して本来阻害的作用をもつものであって，この作用は Fe^{++} による発育促進作用と著しい拮抗的関係にあることが明らかになった。

Table 7. Antagonistic action of Fe^{++} and Mn^{++} on the growth and the activity of sulfate-reducing bacteria strain S M1.

Concentrations of salts added (M)		Incubation time (hrs.)								
		15	24		39		64		112	
$FeSO_4 \cdot 7H_2O$	$MnSO_4 \cdot 7H_2O$	Cells/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Sulfides –S mg/ml	
10^{-6}	0	10^6—10^7	10^7—10^8	0	10^8—10^9	0.109	10^9—10^{10}	0.145	0.136	
10^{-3}	0	10^6—10^7	10^7—10^8	0	10^9—10^{10}	0.214	10^9—10^{10}	0.235	0.166	
10^{-2}	0	10^6—10^7	10^8—10^9	0	10^9—10^{10}	0.240	10^9—10^{10}	0.373	0.267	
10^{-6}	10^{-5}	10^6—10^7	10^7—10^8	0	10^8—10^9	0.119	10^9—10^{10}	0.158	0.158	
10^{-6}	10^{-4}	10^6—10^7	10^7—10^8	0	10^8—10^9	0.093	10^9—10^{10}	0.130	0.133	
10^{-6}	10^{-3}	10^5—10^6	10^6—10^7	0	10^7—10^8	0.001	10^8—10^9	0.080	0.096	
10^{-6}	10^{-2}	10^4—10^5	10^3—10^4	0	1 —10	0	0	0	0	
10^{-3}	10^{-4}	10^6—10^7	10^7—10^8	0	10^9—10^{10}	0.225	10^9—10^{10}	0.248	0.152	
10^{-3}	10^{-3}	10^6—10^7	10^8—10^9	0	10^9—10^{10}	0.203	10^9—10^{10}	0.230	0.168	
10^{-3}	10^{-2}	10^5—10^6	10^7—10^8	0	10^8—10^9	0.019	10^9—10^{10}	0.222	0.223	
10^{-2}	10^{-4}	10^6—10^7	10^8—10^9	0	10^9—10^{10}	0.219	10^9—10^{10}	0.330	0.296	
10^{-2}	10^{-3}	10^6—10^7	10^8—10^9	0	10^9—10^{10}	0.247	10^9—10^{10}	0.313	0.352	
10^{-2}	10^{-2}	10^6—10^7	10^8—10^9	0	10^9—10^{10}	0.177	10^8—10^9	0.294	0.266	

(5) いろいろの金属の不溶性塩類の影響

以上の諸実験で，この細菌の発育および硫酸塩還元作用に与えるいろいろの金属イオンの影響がみられたが，これらはイオンそのものによる阻害的傾向と，H_2S を不活性化させることによる促進的傾向との競り合いの結果があらわれたものと考えられる。それ故，これら金属の不溶性塩類が存在するときには，後者が前者を上まわって最初から促進的傾向が示されるかも知れない。この点を追究するため，微量の Fe^{++} を含む基礎培地に 10 g/L の各種不溶性金属塩を加えて培養した。その結果は第8表に示す通りである。

Table 8. Effects of various insoluble inorganic salts on the growth and the activity of sulfate-reducing bacteria strain SM 1 in the presence of Fe^{++} in different concentrations. (These insoluble salts were added in concentration of 10 g per L.)

Salt added	$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ (M)	Incubation time (hrs.)						
		48		120		288		
		Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Cells/ml	Sulfides –S mg/ml	Reduced sulfate–S mg/ml
Non	10^{-5}	10^9—10^{10}	0.153	——	0.221	10^9—10^{10}	0.126	0.357
* $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$		10^9—10^{10}	0.275	——	0.331	10^9—10^{10}	0.297	0.406
**$4BiNO_3(OH)_2 \cdot BiO(OH)$		10^3—10^4	0	10^8—10^9	0.245	10^9—10^{10}	0.094	0.449
$CdCO_3$		10^3—10^4	0	1 —10	0	0	0	0
$2CoCO_3 \cdot 3Co(OH)_2$		10^2—10^3	0	——	0	0	0	0
$CuCO_3$		0	0	——	0	0	0	0
$MnCO_3$		10^9—10^{10}	0.121	——	0.249	10^7—10^8	0.234	0.372
**$NiCO_3$		10^2—10^3	0	——	0	0	0	0
$2PbCO_3 \cdot Pb(OH)_2$		1 —10	0	——	0	0	0	0
Sb_2O_3		10^3—10^4	0	——	0	0	0	0
$ZnCO_3$		10^3—10^4	0	——	0	0	0	0

Non	10^{-4}	10^9—10^{10}	0.265	——	0.214	10^9—10^{10}	0.107	0.345
* $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$		10^9—10^{10}	0.289	——	0.315	10^8—10^9	0.252	0.375
**$4BiNO_3(OH)_2 \cdot BiO(OH)$		10^4—10^5	0	——	0.183	10^9—10^{10}	0.131	0.442
$CdCO_3$		10^2—10^3	0	——	0	0	0	0
$2CoCO_3 \cdot 3Co(OH)_2$		10^7—10^8	0.012	10^8—10^9	0.076	10^9—10^{10}	0.252	0.436
$CuCO_3$		——	0	——	0	——	0	0
$MnCO_3$		10^9—10^{10}	0.197	——	0.204	10^8—10^9	0.233	0.385
**$NiCO_3$		——	0	——	0	——	0	0
$2PbCO_3 \cdot Pb(OH)_2$		——	0	——	0	——	0	0
Sb_2O_3		10^8—10^9	0.119	——	0.202	10^9—10^{10}	0.186	0.422
$ZnCO_3$		——	0	——	0	——	0	0
Non	10^{-3}	10^9—10^{10}	0.282	——	0.244	10^8—10^9	0.168	0.370
* $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$		10^9—10^{10}	0.306	——	0.434	10^9—10^{10}	0.315	0.390
**$4BiNO_3(OH)_2 \cdot BiO(OH)$		10^9—10^{10}	0.256	——	0.266	10^9—10^{10}	0.157	0.421
$CdCO_3$		——	0	——	0	——	0	0
$2CoCO_3 \cdot 3Co(OH)_2$		10^9—10^{10}	0.383	——	0.422	10^9—10^{10}	0.335	0.453
$CuCO_3$		——	0	——	0	——	0	0
$MnCO_3$		10^8—10^9	0.311	——	0.254	10^8—10^9	0.262	0.484
**$NiCO_3$		10^9—10^{10}	0.012	——	0.233	10^9—10^{10}	0.209	0.327
$2PbCO_3 \cdot Pb(OH)_2$		——	0	——	0	——	0	0
Sb_2O_3		10^9—10^{10}	0.129	——	0.246	10^9—10^{10}	0.204	0.410
$ZnCO_3$		——	0	——	0	——	0	0

* This salt was added in the concentration of 10^{-2} M.

** Sulfides formed were not completely detected by means of the analytical method employed.

すなわち，Fe^{++} が 10^{-5}g atoms/L 存在するときには Bi および Mn の塩類において，Fe^{++} 10^{-4}g atoms/L が共存するときには Bi, Co, Mn および Sb の塩類において，また Fe^{++} 10^{-3}g atoms/L が共存するときには Bi, Co, Mn, Ni および Sb の塩類においてそれぞれ終期に明らかな促進的傾向があらわれたが，その他の塩類では発育が全く阻止された。また，これら促進作用が示されたものについても，その多くは初期には多少とも阻害作用がみられた。

これらの結果は，**実験（3）**でみられたのと殆んど同じ傾向を示すものであって，不溶性塩類の場合でも，おそらく微量に存在するこれら金属のイオンによる阻害作用と H_2S を固定することによる発育促進作用の両者が共にあらわれるものと思われる。そしてこの場合にも，Fe^{++} の濃度によってこれら両者間の平衡が支配されると考えられる。

（6）鉄の形態による促進作用の差異

上で述べたように Fe^{++} はこの細菌の発育に不可欠であるのみならず，ある範囲内ではこれの濃度と比例して発育ならびに硫化物生成作用が著しく促進されることが示された。そこで，これらの促進作用が鉄の形態によってどのように異なるかをみるため，単体または化合物の各種形態の鉄を加えて培養した。その結果は第9表に示す通りである。

すなわち，鉄粉または不溶性第2鉄塩を加えたものでは可溶性第1鉄塩（$FeSO_4 \cdot 7H_2O$）を加えたものにくらべて初期における硫化物生産量は少なかったが，終期においては可溶性第1鉄塩における値を概して上まわる硫化物蓄積量と硫酸塩還元量が示された。このことから，鉄による硫酸塩還元作用の促進には必らずしも Fe^{++} の形を必要とせず，単体または不溶性第2鉄塩でも著しい促進作用をもつようにみえる。不溶性第1鉄塩は調製が困難であるから実験しなかったが，このものもおそらくこれらと同様の促進効果を示すものと思われる。

この場合，これら不溶性の鉄は，細菌の発育ならびに硫化物生成にともなっておこる Eh 降下による還元，硫化水素水（微酸性）による溶解，あるいは局部的な化学電池形成による還元ならびに可溶性化などの作用によって，一旦 Fe^{++} を経て反応促進にあずかるものと考えられる。このことは鉄材の腐蝕と関連してきわめて重大である。

Table 9. Effect of the various iron compounds on the activity of sulfate-reducing bacteria strain SM 1. (Basal medium contained Fe^{++} in the concentration of 10^{-5} M.)

Iron compound added		Incubation time (hrs.)			
		24	96		
Form	Concentration (g/L)	Total sulfides-S mg/ml	"Free H_2S" -S mg/ml	Insoluble sulfides-S mg/ml	Reduced sulfate-S mg/ml
Non	(Fe^{++} : 10^{-5} M)	0.091	0.173	0	0.278
Iron powder	10	0.113	0.091	0.199	0.421
Fe_2O_3	10	0	0.043	0.183	0.320
$Fe(OH)_3$	10	0.046	0.056	0.577	0.726
$FeSO_4 \cdot 7H_2O$	0.5	0.215	0.026	0.205	0.314

(7) Fe^{++} の促進効果に対する Cd 塩の拮抗作用

以上の諸実験を通じて全く発育がおこらなかったのは Cd および Cu の塩類の存在する場合であって，これらは極めて著しい阻害作用をもつようにみえる。Cu^{++} は一般に細胞毒として顕著なものの一つであるからこれによる阻害はうなずけるが，Cd 塩はむしろこの種の細菌の酵素学的研究において，生成される H_2S を捕捉するために菌体を含む反応混液に加えられることが多く，通常その阻害作用は問題とされていない。この点はなはだ疑問に思われたので，つぎの実験でこれを確かめた。

すなわち，いろいろの濃度に Fe^{++} を含む培地に $CdSO_4 \cdot 2H_2O$ または $CdCO_3$ を加えて発育および硫化物生成をしらべた。その結果第 10 表に示すように，Fe^{++} が 10^{-6}g atoms/L 存在するときには $CdSO_4$ 10^{-6} M でも阻害されたが，Fe^{++} が 10^{-3}g atoms/L 存在する場合には $CdSO_4$ 10^{-4} M 以上でのみ阻害が

Table 10. Effect of Cd salts on the growth and the activity of sulfate-reducing bacteria strain SM 1.

Compound added			Incubation time (hrs.)					
			24		48		120	
$FeSO_4 \cdot 7H_2O$	$CdSO_4 \cdot 2H_2O$	$CdCO_3$	Cells/ml	Sulfides-S mg/ml	Cells/ml	Sulfides-S mg/ml	Cells/ml	Sulfides-S mg/ml
10^{-6} M	0 M	0 g/L	10^7—10^8	0.077	10^9—10^{10}	0.204	10^9—10^{10}	0.113
10^{-6}	10^{-6}	0	10^3—10^4	0	10^8—10^9	0.109	10^8—10^9	0.005
10^{-6}	10^{-5}	0	10^4—10^5	0	10^8—10^4	0	10^9—10^{10}	0.203
10^{-6}	10^{-4}	0	1 —10	0	0	0	0	0
10^{-6}	10^{-3}	0	0	0	0	0	0	0
10^{-6}	10^{-2}	0	0	0	0	0	0	0
10^{-6}	0	10	0	0	0	0	0	0
10^{-3}	0	0	10^6—10^7	0.086	10^9—10^{10}	0.260	10^8—10^9	0.118
10^{-3}	10^{-6}	0	10^7—10^8	0.096	10^8—10^9	0.282	10^8—10^9	0.131
10^{-3}	10^{-5}	0	10^7—10^8	0.080	10^9—10^{10}	0.235	10^9—10^{10}	0.123
10^{-3}	10^{-4}	0	10 —10^2	0	0	0	0	0
10^{-3}	10^{-3}	0	0	0	0	0	0	0
10^{-3}	10^{-2}	0	0	0	0	0	0	0
10^{-3}	0	10	0	0	0	0	0	0

おこった。このことは，この細菌の発育および activity が Cd^{++} によって Fe^{++} とは拮抗的な阻害を受けることを示すものである。また，$CdCO_3$ によっても Fe^{++} の濃度にかかわらず発育が全く阻止された。しかし，このことは $CdCO_3$ がこの細菌の硫酸塩還元酵素系を阻害するか否かとは別の問題である。

論　　議

硫酸塩還元細菌の発育に対する Fe^{++} の必要性に関しては既に BUTLIN・ADAMS・THOMAS[9] が淡水性種について明らかにしているが，本実験の結果から海洋性種もこれを不可欠要素として要求することが確認された。このことは，石本・小山・永井[10]および POSTGATE[11] が報告しているように，この種の細菌はチトクローム酵素系をもっているのでこれの形成と密接な関係があるものと考えられる。Fe^{++} の最低必要濃度はおそらく 10^{-8}～10^{-7}g atoms/L 程度の微量で十分と思われるが，上の実験では天然海水中にはこれを満たす程度の Fe^{++} が含まれていないようにみえた。しかし，一般には海水中の Fe^{++} の濃度は平均 3×10^{-8}～3×10^{-7} g atoms/L 程度[12]と考えられ，さらにまたこの細菌が増殖し活動を営むのは海底泥上中であって，この環境には Fe_2O_3 として（塩類，有機物，$CaCO_3$ および水分を除いたものについて）387～600 m mol/1,000 g 程度の鉄が存在する[13]と思われる。そして，鉄が最初から必らずしも Fe^{++} として存在しなくても，この細菌が寒息するような低い酸化還元電位の環境下では初期発育をささえるに足る微量の Fe^{++} は十分得られるものと思われるから，天然の環境下で Fe^{++} 自体がこの細菌の発育制限因子となることは殆んどあり得ないと考えられる*。

また，Fe^{++} は必須要因であるばかりでなく，ある範囲内ではこれの濃度に比例して発育および activity が促進されることが示された。この場合にも，Fe が必らずしも Fe^{++} としてではなく，その他の単体または各種化合態として存在するときでも，一旦発育がはじまればそれにともなう酸化還元電位の低下ならびに硫化物の生成によって Fe^{++} への溶解，還元がつづき，この細菌の発育および activity は加速度的に促進されることが予想される。

鉄以外の金属塩類の場合には，イオンそのものによる阻害的傾向と H_2S の不活性化による促進的傾向とが競り合うためその影響は複雑であったが，いずれの塩でも多少とも Fe^{++} との間に拮抗的関係がみられた。これらのうち，天然の環境下で重要なのは Fe^{++} に対する Mn^{++} の拮抗作用であろう。このことについては既に湖底泥土中での実測結果および粗酵素液での実験結果にもとずいて小山・菅原[14]および村上[15]が明らかにしているが，本報の結果から，海底泥土中においても上と同様の拮抗現象の存在が期待される。

また，上の実験で示されたように，鉄などが多量に存在する場合には硫酸塩還元作用が促進される反面，生産された H_2S が不溶性硫化物として固定されるため遊離硫化水素は比較的少ない。一般に生物に対する直接的毒作用は遊離硫化水素によると考えられるので，この意味では鉄など不溶性硫化物をつくる金属の存在は生物をこの被害から保護するようにみえる。事実，養魚池などにおいて，硫化水素の発生する不良泥質の改良のために鉄を多量に含む赤粘土を投入することがしばしば試みられている。しかしながら，新たに加えられた鉄材によって遊離硫化水素が一時的には減少するとしても，これがやがて硫化物で満たされるであろうということを考えるとその永久的効果は極めて疑わしい。むしろ，この細菌の activity は温度の影響を顕著に受け低温では甚だ微弱である[16]から，天然において鉄などが少ない環境下では低温の季節には酸化，逸散によって硫化物が減少あるいは消失することもあり得ると考えられるのに対して，鉄などが多い環境下ではこの細菌の activity の高低にかかわらず常に多量の硫化物が蓄積されており，これからの H_2S の放出および低い Eh の維持によって絶えず生物に対して不都合な環境を与えるのみならず，更にまたこ

* 小山・菅原[14]の指摘のように，Fe^{++} が FeS によって満たされた後には，Fe^{++} の消失がその後の硫酸還元を制限することはあり得ると思われるが，本来 Fe^{++} の欠乏によってこの細菌の発育が最初から全く阻止されるということは考えられない。

の細菌の生存ならびに activity の維持に対して好都合な条件を持続させる結果になるかも知れない。これらの意味において，鉄など不溶性硫化物をつくる金属の多少は水質汚濁あるいは漁場の老化などの現象と重大な関連があると思われる。

摘　　要

海洋性硫酸塩還元細菌の発育および硫化物生成作用におよぼす種々の重金属塩類の影響をしらべ，つぎの結果を得た。

1. Fe^{++} はこの細菌の発育に必須不可欠であるばかりでなく，ある範囲内ではこれの濃度と比例して発育ならびに硫酸塩還元が促進された。Fe が最初，Fe^{++}，単体または不溶性塩として加えられたときにも硫酸塩還元が促進されたが，おそらく Fe^{++} に変化した後利用されたものと思われる。
2. Bi, Co, Cr, Mn, Pb および Sb の塩類の影響は，金属イオン自体による阻害的傾向と，生産された H_2S を不溶性硫化物として不活性化させることによる促進的傾向とが競り合うため複雑であって，これらを加えると培養初期にはかなりの発育阻害作用があらわれたが，培養終期における硫化物最高蓄積量ならびに硫酸塩還元総量は明らかに増大した。
3. Ni および Zn の塩類は概して阻害的に作用し，Cd および Cu の塩類は著しい阻害作用を示した。
4. Mn^{++} および Cd^{++} は，Fe^{++} の促進効果に対して顕著な拮抗作用をあらわし，その他の金属イオンの場合でも Fe^{++} に対する拮抗関係が多少とも示された。

おわりに，本研究をご指導いただいた京都大学農学部木俣正夫教授，およびご指導ならびにご校閲いただいた京都大学食糧科学研究所門田　元教授に厚くお礼申し上げる。

文　　献

1) 畑　　幸彦：1960. 本報告，**9**，329—345.
2) 畑　　幸彦：1960. 本報告，**9**，347—362.
3) 木俣正夫・門田　元・畑　幸彦・田島卓明：1955. 日本水産学会誌，**21**，113—118.
4) 畑　幸彦・三好英夫・門田　元・木俣正夫：1959. 本報告，**8**，135—145.
5) WARING, W. S. and C. H. WERKMAN：1942. *Archiv. Biochem.*, **1**, 303—310.
6) 富山哲夫・神崎嘉瑞夫：1951. 日本水産学会誌，**17**，115—121.
7) 富山哲夫・小島良夫：1953. 日本水産学会誌，**18**，687—690.
8) 三宅　泰雄：1954. "水質分析"，生活百科刊行会，東京，p. 110.
9) BUTLIN, K. R., M. E. ADAMS and M. THOMAS：1949. *J. gen. Microbiol.*, **3**, 46—59.
10) ISHIMOTO, M., J. KOYAMA and Y. NAGAI：1954. *J. Biochem.*, Tokyo, **41**, 763—770.
11) POSTGATE, J. R.：1956. *J. gen. Microbiol.*, **15**, 186—193.
12) SVERDRUP, H. U. et al.：1949. "The Ocean", 3rd ed., Prentice-Hall, New York, pp. 176.
13) Ibid., pp. 991.
14) KOYAMA, T. and K. SUGAWARA：1953. *J. Earth Sci.*, Nagoya Univ., **1**, 24—34.
15) 村上　枝彦：1952. 愛知学芸大報告.，**1**，77—79.
16) 木俣正夫・門田　元・畑　幸彦・田島卓明：1955. 日本水産学会誌，**21**，109—112.

魚鱗箔採製に関する二、三の実験※

上田　正・長　親志・村里隆司・松沢定五郎

On Some Experiments for Preparing Pearl Essence※

By

Tadashi Ueda, Chikashi Osa, Takashi Murasato
and Jōgorō Matsuzawa

Since the chemi-pearl have been introduced, the applications of pearl essence are limited to the lustrous agents for higher grades of imitation pearl, pearl celluloid, acryl resin and others, but for the ordinaty grades of them 〔except acryl resin〕 they give way to the chemi-pearl.

The preparing methods in Japan are as follows,

a) Cutlas fish are only processed to prepare pearl essence for practical easiness.

b) Scrub off the surface film of the fish with blunt knife. The scrubbed mass contain about 20—30 % of crystal guanine.

c) The scrubbed mass are mixed with 10 % of petroleum, and stored at low temperature to receive the next process.

d) The mass are stirred in 4 times in volume of petroleum to separate the crystal guanine into the liquor.

e) Then the petroleum solution of guanine is fractioned from the mass to refine the pearl essence. The separation of guanine are repeated 6—7 times to the state that the mass separate guanine no more practically. So the residue is usually rejected as waste, yet it contains 5 % of crystal guanine.

f) The further process, refining methods are practised as other countries, i.e. removing fish oil and impurities, and kneading the refined materials into concentrated cellulose solution to finish the cellulose lacquer of pearl essence. In a final yield in commerce, congregation of crystal guanine particles occurs often in the storage, and about 10 % of the yield are unable to use.

In this paper following details are discussed from the data of the experiments.

(1) Preserving method for the scrubbed mass: Cutlas fish are caught only in their fishing season. This nesseciates to store the scrubbed mass to prepare all the

※ 水産講習所研究業績　第306号,　1960月2月11日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 306.
Received　Feb. 11, 1960.

year round. The mass are usually stored at 0°C. This preserving method makes the yield from them inferior when stored for more than 1 month, so the other methods are researched.

In applying the preserving agents, it is profitable to use KCNS or the agents which disolve proteins, and unfit to use Na_2SO_4 or the agents which precipitate protein, for the latters make the separation difficult and the separated pearl essence lusterless (See table 1, 2).

(2) Separating method of crystal guanine from the waste: Following process is devised to separate 3 % of crystal guanine from the residue. The residue are diluted to twice times with water, and warmed to about 60°C. This digests the tissue, which entangles the guanine, to make it separable. The digested material is dehydrated to about 59 % of moisture. From them it is possible to separate guanine by stirring in petroleum. In case the moisture of them is more than that, the percentage of separated guanine becomes lower, and in case of less moisture, the percentage becomes higher, but the yield holds so much impurities which are unfit for refine(See table 5).

(3) Congregational reaction of guanine particles in cellulose lacquer of pearl essence: The origin of this reaction is researched. In the unadequately refined yield the reaction occurs, and no reaction in well refined one. To the well refined one black matters, which are separated from the course of refining process, are mixed to store, then the reaction occurs. Therefore the reaction, at least, owes partly to the black substances (melanoids) (See table 6).

諸　　言

わが国における魚鱗箔の利用はケミパールが市販されるようになって以来，従来の広範な利用面は局限されて来たが模造真珠，セルロイド真球素地などの高級品，またアクリル樹脂その他の真珠光沢剤として利用されている。

わが国で行なわれている魚鱗箔採製方法はつぎに示すとおりである。

a) 原料は“たちうお”を専ら使用している。

b) 鈍刀をもって魚体表面を削り取る。このものは結晶グアニンを20～30％含む。(通常親箔という。)

c) 親箔には揮発油10％を混和し，低温貯蔵を行なう。

d) 親箔を3～4倍容の揮発油中に攪拌し結晶グアニンを油層に分散懸遊させる。揮発油分散は6～7回繰返すと，実際的には結晶グアニンは分散しなくなる。然しこの残渣中にはなお約5％の結晶グアニンを含有する。

e) 懸遊液より結晶グアニンを分取し，精製する。

外国において行なわれる方法は，原料に“たちうお”用いず，にしんその他を用いている。その方法は：

f) 魚体の鱗を水中に剝ぎ落し，かつ攪拌して水層に分散する結晶グアニンを捕集する。

g) 爾後の精製過程には日本法と大差がらい。すなわち魚油，その他の不純物を除去し，セルロイド溶液中に混合，練り合わせてセル箔にする。

市販セル箔（ドープス）は時日の経過とともに凝集反応を起し，その約10％は粗粒となって使用耐えないものとなることがしばしばである。

われわれは上記の中で，親箔の貯蔵，残渣よりグアニンの分離，セル箔中のグアニンの凝集反応，につき若干の簡易な試験を行なった。

1. 原料（親箔）の貯蔵

親箔の変性は著しく速かである。"たちうお"は他魚と同様に漁期があるのでこれを貯蔵する必要がある。普通親箔を0°Cに貯蔵する方法をとっている。この方法の場合には1ヵ月もするとその精製箔はかなり品質のおとるものとなる。そのため貯蔵剤を用いて貯藏期間を延長することの可能性を検討した。

実 験—I

実験に供した試料は"たちうお"魚体より削り落した得た親箔を使用し，貯蔵剤は第一表に示した，蛋白

Table 1. Observation on the scrubbed mass, preserved with various reagents.

Preservatives.	States of the mass.	Pearl-essence, separated.
——	Spoiled slightly on the 2nd day.	Separable for 25 days.
KCNS(10%)	Good for 2 months or more.	Separable for 2 months or more.
As_2O_3(2%)	Good.	Separable for 2 months or more.
NaCl(20%)	Unspoiled for 2 months.	Separable for 2 months or more, but the separated amount are much decreased.
Na_2SO_4(18%)	〃	〃
Salicylic acid	〃	Separable for 2 months or more, but the yield holds more impurities.
Acetic acid	〃	〃
NH_4OH(36%)	Good.	Separable for 2 months or more, the yield are the most lustrous.
Na_2CO_3(15%)	Unspoiled for 2 months or more.	Pearl-essence is deformed partly.
Formaldehyde (5%)	〃	Pearl-essence, separated, is no lustrous.

Table 2. Observation on the aqueous suspensoids of crude pearl-essence.

Preserving agents.		State of the suspensoid.	Preserving agents.		State of the suspensoid.
Name	%		Name	%	
NaCl	5	Cloudy precipitates occur to disappear the luster.	KCNS	4	Unchanged for 6 days.
〃	10	〃	〃	6	〃 10 days or more.
〃	20	〃	〃	6	〃 60 days.
Na_2SO_4	5	〃	〃	6	〃 90 days.
〃	10	〃	〃	6	〃 101 days.
〃	20	〃	Toluol	1 drop	〃 6 days.
Salicylic acid	0.5	〃	NH_4OH(36%)	10	〃 7 days.
〃	1	〃	〃	50	〃 15 days or more.
〃	3	〃	Acetic acid	5	Unchanged for 7 days, but changed blackish in colour at 15 days.
Arcenic acid	0.1	Unchanged for 10 days.	Na_2CO_3	5	Its luster disappears at all in a day.
〃	0.2	〃	〃	10	〃
〃	0.3	〃	〃	15	〃
KCNS	1	Unchanged for 5 days.			
〃	2	〃 5 days.			

質を溶解するもの，またそれを固定するものなど9種に亘り試用し，時日の経過とともに試料の腐敗臭の有無，およびグアニンの抽出状況を観察した。

第2表に試用せる試料は，“まえそ”魚鱗箔原料の水懸遊液である。一般に魚鱗箔原料の水懸遊液は最も変性し易いものである。第1表，第2表の何れも，添加貯蔵剤が含有蛋白質に与える作用そのままが貯蔵剤としての良否を決定している。すなわち蛋白質を沈澱または固定する作用のある貯蔵剤は，魚鱗箔の収率，および光沢をともに害し，溶解するかまたは沈澱させない貯蔵剤は良い成績を挙げている。特に NH_4OH KCNS は良好結果を示している。

実　験－Ⅱ

上記のごとく良好結果を示した KCNS について，さらに検討するため，“まえそ”魚鱗箔原料の水懸遊液を試料として試験を行なった。KCNS を試料 200 g に対して，それぞれ1，2，4……g と第3表に示す如く試用し，懸遊液および結晶グアニンの状態を観察した。

Table 3. Observation on the aqueous suspensoids of pearl essence by KCNS solution (Fish used *Saurida undosquamis.*).

Weight of sample. (g)	Weight of KCNS. (g)	A state of the suspensoid for storing days.													
		1 day		2 days		3 days		4 days		5 days		16 days		21 days	
		L	S	L	S	L	S	L	S	L	S	L	S	L	S
200	0	−	+	−	+	−	+								
200	1	+ slightly	+	−	+	−	+								
200	2	+	−	−	+	−	+								
200	4	+	−	−	+	−	+								
200	8	+	−	+	−	+	−	+	−	+ slightly	+	+ slightly	+	−	+
200	15	+	−	+	−	+	−	+	−	+	−	+	−	+	−
200	20	+	−	+	−	+	−	+	−	+	−	+	−	+	−

(L……luster, S……stink.)

なお“こいち”魚鱗箔原料の水懸遊液に7％（重量比）のKCNS を添加し，これを放置し，懸遊液および結晶グアニンの状態を観察した。

Table 4. Observation on the aqueous suspensoids of crude pearl essence by 7 % KCNS solution.

No.	KCNS (%)	A state of suspensoid.
1	7	Unchanged for 60 days.
2	7	Unchanged for 2.5 years.

第3表，第4表においては，水分散の方法にて得られる魚鱗箔原料の水懸遊液では，KCNS 7％（重量比）を添加すればかなり貯蔵期間を長くしまた良質の箔を得る。

2.　残渣より結晶グアニンの分離

前述のごとく，親箔より結晶グアニンを抽出した，残渣中にはなおも5％のグアニンを含有している。普通これは廃棄されている。この残渣から結晶グアニンを再抽出する方法を次記のごとく考案した。

Ⅰ　予　備　処　理

残渣中には魚体から削り落された，かなり大片の皮組織が多量混入しており，そのままの状態で揮発油抽出を行なっても魚鱗箔の分散量は極めて少ない。まず予備処理として，残渣に2倍量の温湯（50～60°C）を加え静かに攪拌を続ける。この間温度に低下しないようにする。

1～2時間，経過すると残渣は完全に泥状物となってくる。この泥状物を遠心脱水または乾燥などにより脱水を行なう。脱水の適度については後述する。この予備処理の効果についてはつぎの利点が考えられる。

1. 適温における加水，攪拌は皮をゼラチン化せしめまたその他の蛋白質の自己消化を促し，また含有魚鱗箔の表面を清浄にして親油性を増大させる。
2. 大片の皮組織などの折れ曲った部分に存在する魚鱗箔は遊離され揮発油とし接触を促す。

Ⅱ　抽出時の最適水分量

予備処理を終った材料は脱水を行ない，最適水分量にして揮発油抽出を行なう。

揮発油抽出においては，魚鱗箔と蛋白質様不純物とは全く逆な動きをする。すなわち魚鱗箔は油層に，不純物は残渣中に残る。しかし残渣中の水分量が過度に少なくなると，不純物が油層に移行してくる。また水分量の過度に多い場合等には箔と揮発油との接触が妨害される。

予備処理を終った材料中の水分量と箔抽出量との関係は第5表に示す。

Table 5. The relation between the moisture of the dehydrated material and the yield of crude pearl essence from it (Sample was residue of oiled crude pearl essence.).

No.	Weight of sample. (g)	Moisture. (%)	Weight of extract. (g)	Yield. (%)	Yield. (%) (after water-wash.)	Impurity. (%)
1	1000	73.5	50	5.0	3.6	1.4
2	630	59.0	40	6.3	4.1	2.2
3	610	48.8	35	5.7	2.5	3.2
4	630	43.0	31	4.9	2.6	2.3
5	684	33.5	36.5	5.3	2.5	2.8
6	1260	19.5	94.5	7.5	2.4	5.1
7	1290	15.6	99.5	7.7	3.6	4.1

第5表の結果より最適水分量を求めると 59 % となる。水分量 73.5 % においては，水洗除去可能である，不純物（主として melanoid）の混入は少ないが，魚鱗箔の収率は低い値を示す。20 % 以下の水分量の場合には不純物の混入が増大し，爾後の工程にも悪影響をおよぼす。

3.　セル箔中のグアニンの凝集反応

前述のごとく精製された結晶グアニンは，普通セル箔として市販保存，あるいは直ちに使用されている。この間にセル箔中の結晶グアニンは，互に附着し，粗粒となる，すなわち凝集反応を起すことがある。このものは再び溶剤を用いて分散を行なっても，分散を起さず，光沢はなくなる。セル箔中 10 % 程度のものが凝集して粗粒を形成することはしばしばである。

Ⅰ　不純物の大別

揮発油抽出された魚鱗箔より精製パールエッセンスに至る間に除かれる不純物としてはつぎに示すものに大別される。

1. 水洗により除かれる黒色物（melanoid 系）。
2. ソープレスソープ洗浄により除かれる，白色物。
3. 砂粒。
4. 魚油。

この中で砂粒，魚油は洗浄時の揮発油再分散に完全に除かれる。

黒色物，白色物の残存が精製パールエッセンス（セル箔）に，どのような影響をおよぼすかを，“たちうお”魚鱗箔（精製されたもの）を用いて試験した。

実　　験

精製魚鱗箔（たちうお）に，水洗工程中は得た黒色物，または白色物を混入し，セルロイド液にて練り合わせ，セル箔とし15日間の貯蔵後にそれの分散試験を行なった。試料 3.00 g を 500 cc 容メスシリンダーにとり，これを醋酸ブチルで稀釈分散させ底に沈降した粗粒を測定した。その結果は第6表に示す通りであった。

Table 6. The relation of dispersion and impurity.

Wt. of material, mixedwith :			Unseparable matters.	
Refined pearl essence (g)	Black impurity (g)	White impurity (g)	Weight (g)	Wt. of %
3.00	0	0	0.0128	0.43
3.00	0.04	0	0.0546	1.82
3.00	0.20	0	0.0655	2.18
3.00	0.05	0.05	0.0343	1.14
3.00	0	0.10	0.0149	0.49

Refined pearl-essence and black impurity (separated from the couse of the refining) or white substance (separated from the process of soapless-soap washing) are kneaded thoroughly in cellulose racquer and stored 15 days. The mixed and stored mass are cautiously separated crystal guanine from them by butyl-acetate, and the unseparable residue are determined.

第6表から，白色物は殆んど粗粒生成の原因とならず，黒色物は粗粒生成の一要因となっていると考えられる。粗粒の形成を避けるには抽出時における黒色物の混入はできるだけ防ぎ，混入したそれらは精製工程にて完全に除く必要がある。

要　　約

1. 親箔貯蔵法。貯蔵剤を適用する場合は KCNS あるいは蛋白質溶解性の貯蔵剤を利用すると良好結果が得られる。Na_2SO_4 あるいは蛋白質沈澱性の貯蔵剤は不適当である。これはグアニンの分離を困難にし，かつその光沢を損ずるためである。

2. 残渣よりグアニンの分離。次の方法によれば残渣からさらに約3％のグアニンを分離し得る。すなわち，残渣を水で2倍に稀釈し，加温し 60°C 前後に保つ。グアニンを包被した組織が溶解，消化して，グアニンを遊離する。これを脱水して水分量を 59 % 付近にして揮発油中に攪拌するとグアニンは分離し得る。水分量がより以上の場合はグアニンの分離量が低下し，またより以下の場合には，その分離量は増加するが，不純物の混入量が増大し爾後の精製を困難にする。

3. セル箔中のグアニンの凝集反応。この反応は，よく精製されたセル箔中には起らない事実がある。精製不充分のものに起る，また精製品中に，その精製途中に分離した黒色物（melanoid）を添加するとこの反応は起る。したがって melanoid 類が少なくとも凝集反応の一要因と考えられる。

文　　献

1. Donald, K. & Tressler, PH. D. : 1923. Marine products of Commerce.
2. 宝来　利一：水産工芸.

ウニの塩辛に関する研究—Ⅱ.

ウニ塩辛の貯蔵中における成分変化に およぼす食塩およびアルコールの濃度の影響について※

河内正通・畑　幸彦

Studies on "Uni-Shiokara" ——Ⅱ.
Influences of Salt and Alcohol upon the Changes in Chemical Composition of "Uni-Shiokara" During the Storage※

By

Masayuki KŌCHI and Yoshihiko HATA

The authors have previously reported that changes in chemical composition of "UniShiokara" during the storage were remarkably retarded as compared with those of "Fish-Shiokara" during the ripening process. This may be due to the inhibitory effect of alcohol contained in the former "Shiokara" on the autolytic and microbial decomposition of the constituents.

The present paper is concerned with the influences of the concentrations of salt and alcohol upon the changes in chemical composition of "Uni-Shiokara" during the storage at room temperature in relation to its commercial quality.

The results obtained are shown in Tables 1—3 and Figs. 1—6, and may be summarized as follows :

1) During the storage the amounts of low molecular nitrogen compounds and reducing sugars more or less increased, whereas the pH value considerably decreased.
2) The higher the concentration of salt and alcohol added to "Uni-Shiokara", the slower the changes in chemical composition of it occurred.
3) The commercial quality (color, texture and taste) of "Uni-Shiokara" was markedly influenced by the concentrations of salt and alcohol in it.

緒　　言

前報[1]において，著者らはウニ塩辛の貯蔵中における成分変化は比較的微弱であることを明らかにしたが，

※ 水産講習所研究業績　第307号，　1960年2月11日 受理.
Contribution from the Shimonoseki College of Fisheries, No. 307.
Received Feb. 11, 1960.

これは下関地方で普通に行なわれているような，かなり多量の食塩およびアルコールを添加したものについてであった。一般に，自家消化酵素作用および微生物による分解作用はともに食塩ならびにアルコールによって大きな影響を受け，また蛋白質の溶解性あるいは凝固性もこれらの濃度に大きく左右される[2]。したがって，ウニ塩辛に加えられる食塩およびアルコールの量は，これの成分変化ならびに物理的性質に対して重大な影響を与えることが予想される。

本報ではこれらの点を究明するため，食塩およびアルコールを種々の濃度に加えてウニ塩辛を製造し，貯蔵中の諸変化におよぼすこれらの濃度の影響について検討した結果を報告する。

実　　験

試　料：北浦産の新鮮原料（バフンウニ，70％：ムラサキウニ，30％）を用い，第1表に示す量の食塩およびアルコールを加えて各種試料を調製し，密栓して室温に放置した（1958年7月29日調製）。

Table 1　The preparation of "Uni-Shiokara." The gonad of sea urchin (*Strongylocentrotus pulcherrimus*, 70 % : *Heliocidaris crassispina*, 30 %) freshly caught at Kitaura were used as raw materials. The experiments were started on Jul. 29, 1958.

Sample number	Concentrations of additions	
	NaCl(g/100g of raw materials)	Absolute ethanol (ml/100 g of raw materials)
1	5	14
2	10	14
3	15	14
4	10	7
5	10	20
6	5	7
7	15	20

測　定：前報と同様の方法で，経時的に各種化学成分および微生物の消長を測定した。なお今回は，製造後約1カ月および6カ月において色調，硬さおよび香味などについての官能的検査もあわせ行なった。

結　果：測定の結果は第1～6図および第2ならびに3表に示す通りである。

すなわち，水溶性*，非蛋白態*ならびにアミノ態窒素量の変化については，アルコール添加量の等しい（14 ml/原料100g）1，2および3の各 sample の間では概して食塩濃度に反比例して増加量が大きく，一方食塩濃度の等しい（10g/原料100g）sample 2，4および5ではアルコール添加量に反比例してこれらの増加が著しかった。また，食塩，アルコールがともに少ない sample 6ではこれらの低級窒素化合物の生成がはなはだ大きかったのに対して，両者の添加量がともに大きい sample 7ではこれらが極めて低い値に止まった。また揮発性塩基窒素については甚だ錯綜した結果があらわれたが，概して上と同様の傾向がみられた。そして揮発性塩基窒素を除くその他の窒素成分の変化は，初期1～2カ月位の間に比較的著しくその後ははなはだ緩慢であったが，揮発性塩基窒素の生成はその後も進行し，ことにアルコール添加量の少ない sample 4および6では約1カ年後には極めて高い値となり，明らかに腐敗と認められた。還元糖の変化については食塩，アルコールの添加量がともに多い sample 7を最低とし，これらがともに少ない sample 6を最高として，この間に食塩，アルコールの濃度に応じた増加がみられた。この変化も概して初期1～2カ月位でほぼ平衡となったが，食塩，アルコールがともに少ない sample 6およびこれらのいずれかが少な

* これらの窒素は，食塩ならびにアルコールの濃度によって直接影響されるから，試料の調製直後においてもすでに大きな差異がみられた。

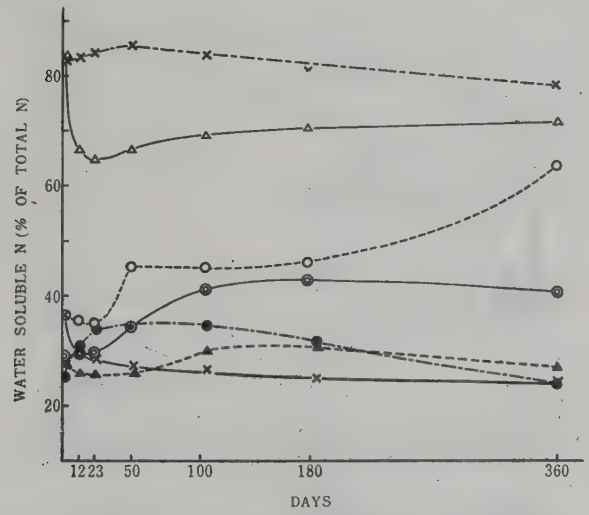


Fig. 1. Change of the amount of water soluble nitrogen in "Uni-Shiokara" during storage at room temperature.
---○---, Sample 1; —◎—, Sample 2; --●--, Sample 3; —△—, Sample 4; ---▲---, Sample 5; —×—, Sample 6; —×—, Sample 7.

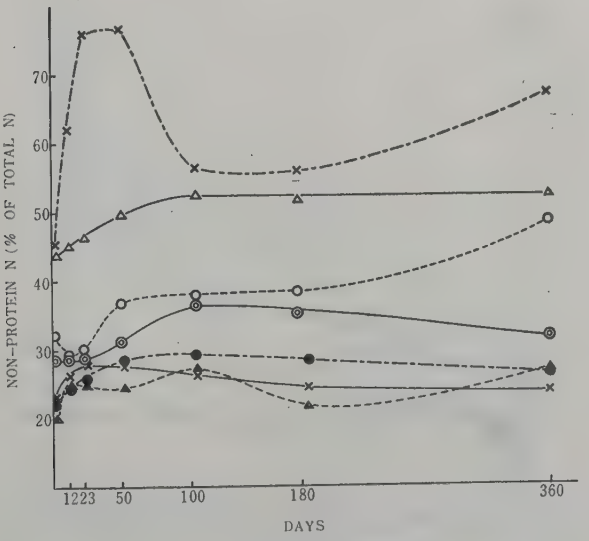


Fig. 2. Change of the amount of non-protein nitrogen in "Uni-Shiokara" during storage at room temperature. Marks were the same as those employed in Fig. 1.

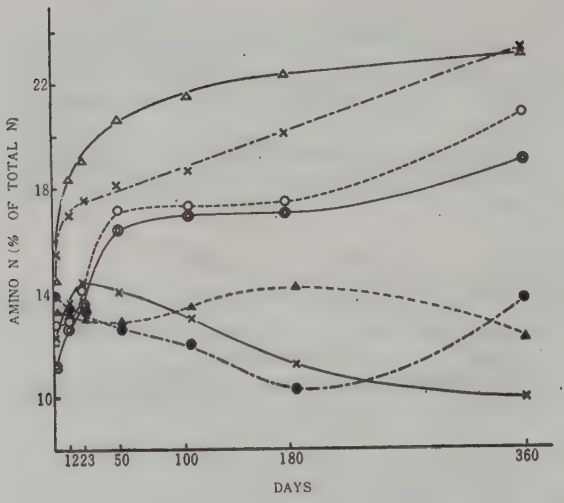


Fig. 3. Change of the amount of amino nitrogen in "Uni-Shokara" during storage at room temperature. Marks were the same as those employed in Fig. 1.

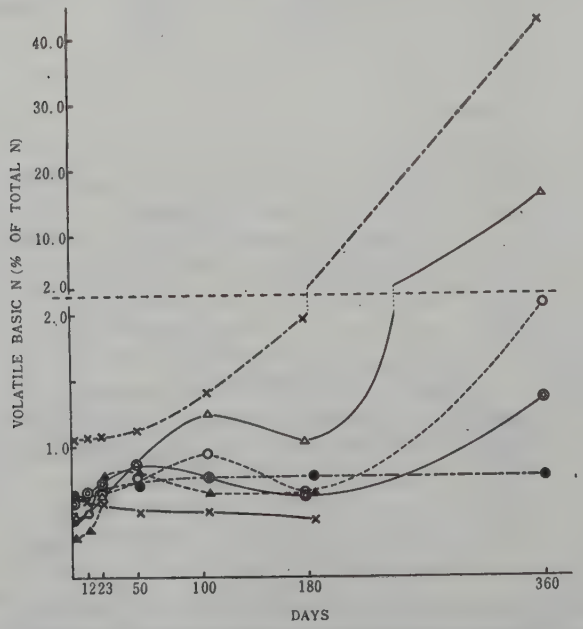


Fig. 4. Change of the amount of volatile basic nitrogen in "Uni-Shiokara" during storage at room temperature. Marks were the same as those employed in Fig. 1.

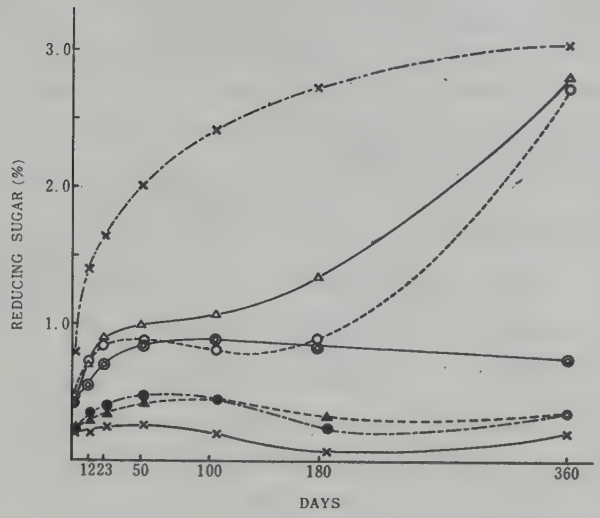


Fig. 5. Change of the amount of reducing sugar in "Uni-Shiokara" during storage at room temperature. Marks were the same as those employed in Fig. 1.

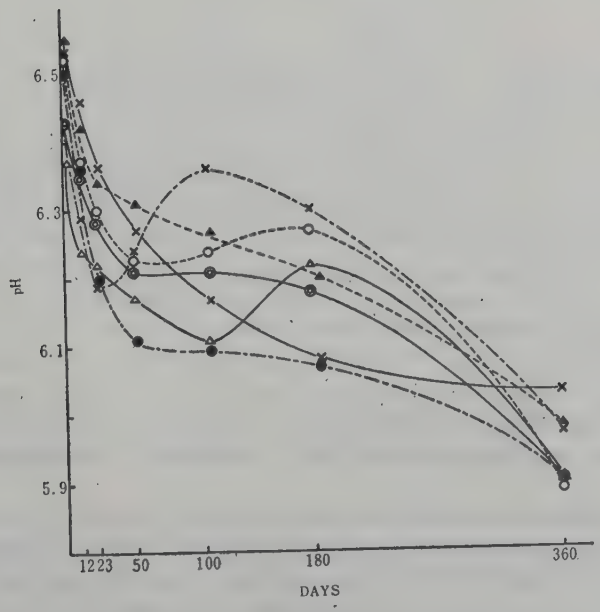


Fig. 6. Change of pH value in "Uni-Shiokara" during storage at room temperature. Marks were the same as those employed in Fig. 1.

い sample 1および4では，その後も増加が続き約1カ年後には著しく増大した。つぎに pH 価の変化については，いずれの sample でも初期1～2カ月の間にかなり急激に降下した。一般にその後も徐々に降下したが，sample 6では約3カ月後に，sample 1および4では約6カ月後に一旦かなりの上昇がみられた。そして，約1カ年後には各 sample 間に多少の差異はあるがすべてほとんど6.0付近となった。

Table 2. Number of micro-organisms contained in "Uni-Shiokara" during the storage at room temperature (Viable cells in 1 g of sample).

Sample number	Medium* employed for plate counts	Time after preparation of samples								
		3 hrs.	1	5	12	23	50	104	181	387 days
1	A	2×10^4	——	8.4×10^3	1.4×10^4	4×10^3	5×10^3	8×10^2	2×10^2	1.4×10^3
	B	1×10^3	——	2.6×10^2	**	4×10	6×10^2	1.4×10^2	2×10	2.7×10^2
	N	——	——	——	——	——	——	4×10	**	3.5×10
	P	1.8×10^2	——	1×10^2	6.2×10^2	1×10	2×10^2	**	2×10	——
2	A	8×10^3	——	1.8×10^3	1.4×10^3	1×10^3	5×10^2	1.4×10^2	6×10	1.5×10^2
	B	1.8×10^3	——	1×10^2	4.8×10^2	1×10^2	5.2×10^2	2×10	2×10	1.5×10^2
	N	——	——	——	——	——	——	2×10	2×10	2.5×10^2
	P	1.6×10^3	——	2×10	3.4×10^2	7×10	2×10^2	1×10^2	**	4.7×10^2
3	A	——	5.2×10^2	2.6×10^3	8×10^2	2×10^2	8×10^2	2.2×10^2	1.2×10^2	1.8×10^2
	B	——	3.6×10^3	6×10^2	4×10^2	2×10	3.8×10^2	8×10	2×10	2.3×10^2
	N	——	——	——	——	——	——	4×10^2	4×10	3.5×10^2
	P	——	4.4×10^2	4×10^2	4×10^2	8×10	2.4×10^2	6×10	4×10	9×10
4	A	5.6×10^4	——	2.4×10^3	1.2×10^4	1×10^4	1.6×10^2	6×10	1×10^2	4.3×10^2
	B	1×10^4	——	2.6×10^2	2×10	4×10	4.2×10^2	4×10	2×10	2×10
	N	——	——	——	——	——	——	2×10	4×10	1.9×10
	P	4.6×10^3	——	6×10	4.8×10^2	6×10	1.2×10^2	8×10	**	5×10
5	A	——	8×10^2	2.8×10^3	6×10^3	2×10^2	1.0×10^3	8×10^2	4×10^2	9×10
	B	——	1.8×10^3	4×10^2	1.2×10^2	6×10^2	4×10^2	1×10^2	2×10	1.8×10^2
	N	——	——	——	——	——	——	4×10^2	1.8×10^2	——
	P	——	6×10^2	8×10^2	6×10	8×10	1.2×10^2	4×10	4×10	1.9×10^2
6	A	8.3×10^4	——	4.8×10^3	8×10^2	6×10^2	4.4×10^3	6×10^2	6×10	4.4×10^2
	B	4.8×10^3	——	6.8×10^2	1×10^2	8×10	4×10^2	1×10^2	1×10	2.5×10
	N	——	——	——	——	——	——	**	4×10	——
	P	1.1×10^3	——	3×10^2	1.8×10^2	1×10	6×10	**	8×10	4×10
7	A	——	1.4×10^3	6×10^2	**	6×10^2	3.2×10^2	6×10	4×10	2×10
	B	——	2.4×10^2	1.6×10^3	6×10	2×10	1.8×10^2	1.3×10^3	**	1.6×10
	N	——	——	——	——	——	——	8×10	4×10	——
	P	——	6.8×10^2	2×10^2	3×10^2	4×10	3.0×10^2	1×10^2	4×10	——

* Medium A : Nutrient broth agar.
〃 B : Nutrient broth agar added with 10 % NaCl.
〃 N : Potato glucose agar.
〃 P : Potato glucose agar added with 10 % NaCl.
** Less than 10 cells.

微生物の消長については各 sample 間に大差はみられなかった。そして，いずれの sample でも貯蔵中にはげしい変動はなく発育を抑制された環境下で漸次減少する傾向が示され，約6カ月後にはほぼ最低となった。しかし約1カ年後にはいく分増加の様子がみられたが，これは室温の変化* とある程度関連があるのではなかろうか。

一方，官能的検査の結果についてみると，アルコール添加量の等しい sample 1，2および3においては食塩濃度の少ないほど色調は暗色を帯び，原料の軟化がはなはだしかった。また，食塩濃度の等しい sample 2，4および5においては，アルコール添加量の少ないものが概して暗色化し軟化の程度が大きかった。食塩，アルコールのともに少ない sample 6では暗色化と軟化が特に著しく，これらがともに多い

* 実験の開始が7月末であったから，181日後は冬季であり 387日後は夏季に当る。

Table 3. The results of organoleptic observations on "Uni-Shiokara" stored at room temperature.

Sample number	Time after preparation of sample (days)						
	23			181			
	Color	Texture	Flavor and taste	Color	Texture	Flavor and taste	Order on commercial quality
1	reddish orange	soft	sweet ; savoury	dark reddish orange	soft, pasty	sweet ; savoury	2
2	bright reddish orange	moderate	sweet ; savoury	reddish orange	moderate	sweet ; savoury	1
3	bright reddish orange	moderate	salty	reddish orange	moderate	salty	4
4	dark reddish orange	soft	sweet, fishy	dark reddish orange	soft, pasty	sweet, slightly fishy	3
5	reddish orange	soft	salty, alcoholic odor	dark reddish orange	soft	salty and bitter, alcoholic odor	5
6	dark orange	partially liquefied	sweet, fishy	dark orange	liquefied	sweet, fishy	7
7	bright reddish orange	hard	salty and bitter, alcoholic odor	partially faded	hard	salty and bitter, alcoholic odor	6

sample 7では最初色調は鮮かであったが，貯蔵中にかえって褪色し，また粒状が極端に保存されて硬すぎた。呈味については，食塩およびアルコールの少ないものではアマ味が強く，これらが多いものではカラ味が強くさらにニガ味が感じられた。

考　　察

以上の結果，ウニ塩辛の貯蔵中における成分変化は食塩およびアルコールの添加量の影響をともに受け，これらの濃度の大きいものほど抑制されることが明らかになった。そして，アルコールが14 ml/原料100 g*の濃度に加えられたときには，食塩15 g/原料100 g では変化ははなはだ微弱であって，このような高濃度下では微生物のみならず自家消化酵素の作用も著しく阻害されることがわかった。また食塩 5～10 g/原料100 gではかなり分解が進んだが，このように比較的食塩が低濃度の場合でも，ことに初期約6カ月位までは揮発性塩基窒素の増加が極めて僅かであったことから，14 ml/100 g 程度のアルコールを加えれば，自家消化はいく分進むが防腐の目的はほとんど達せられると思われる。しかし，ことに食塩5 g/原料100 g のものでは約6カ月を過ぎると揮発性塩基窒素の増加は急激となった。

一方，食塩が10 g/原料100 g*存在するときには，アルコール20 ml/原料100 gでは変化がはなはだ小さかったが14 ml/原料100 gではかなり分解が進み，7 ml/原料100 g では極めて変化が大きく6カ月から1カ年の間に腐敗した。

また，原料100 gに対して食塩15 g，アルコール 20 ml が加えられたものでは成分変化がほとんど阻止されたのに対して，食塩5 g，アルコール 7 ml のものでは変化が極めて急激で6カ月以後に明らかに腐敗した。

これらの成分変化と品質との関係については，品質が呈味成分のみならず物理的性質とも密接に関連する上，これを判定する個人の嗜好によっても大きく支配されるので一概には論じられない。しかし，本研究室教室員による官能的検査の結果（第3表）をみると，一般には適度の硬さを保ち比較的カラ味が少なくアマ味の多いものが好まれるようであって，他の一般塩辛類の場合にいわれるようなアミノ酸量との直接的相

* これらの濃度は現在下関地方でつくられている製品についての標準のようである。

関はみられなかった。製品の硬さは食塩，アルコールの，原料に対する直接的作用と貯蔵中の変化におよぼす間接的作用の両者によって支配されよう。

すなわち，食塩およびアルコールは濃度に応じて原料蛋白質の凝固，溶解あるいは溶出に複雑に関係するが，供試濃度付近では概してこれらが高濃度のときほど硬く，また成分の分解にともなう粒状の崩壊，軟化は一般にこれらが高濃度のときほど小さかった。また製品のアマ味，カラ味あるいはニガ味は，添加物自体による呈味あるいは刺激によるとともに，上述の還元糖* 生成量の差異が大きく影響しているようであって，これら添加物の濃度が低いほどアマ味が強かった。それ故，官能的検査による総合的品質の第1順位は添加物量の最大と最小との間にみられた。

以上の結果を通じて，現在下関地方で行なわれている食塩およびアルコールの添加量は総合的品質に対しておそらく最適の濃度付近であると思われる**。そして，実験の濃度範囲内では，成分変化におよぼす添加物量の影響は食塩よりも概してアルコールの方がより大きいようであって，アルコール量を約半分程度に減らすと，大量の食塩を加えるかまたはその他の補助的手段を用いない限り腐敗を防ぐことはできないし，また，官能的にも未だ蛋白凝固が不充分でなまぐささを感じさせるので好ましくない。一方，食塩の量を半分程度に減らすと腐敗は避けられるにしても成分の分解，軟化および暗色化が進むので，短時日のうちに消費するかまたは冷蔵*** することが望ましい。

そして，冷蔵などの手段と併用してある程度これらの添加量を少なくした方が現在の嗜好の傾向からいって，より好ましいようである。

なお，以上の実験で成分変化の速度あるいは割合は調製初期1～2カ月および6カ月～1カ年の間に比較的大きかったが，これはおそらく気温の高低とも関連があるものと思われ，ことに貯蔵後期は気温上昇期に相当するから，この意味においても単なる時間的因子だけでなく季節的因子をも充分考慮に入れることが肝要であろう。

摘　　要

ウニ塩辛の貯蔵中における成分変化におよぼす食塩およびアルコールの濃度の影響を検討して，つぎの結果を得た。

1. 貯蔵中，低級窒素化合物ならびに還元糖の量が多少とも増大し，pH 価がかなり低下した。
2. 成分変化の程度は食塩およびアルコールの添加量にほぼ反比例した。
3. 食塩およびアルコールの添加量と色調，硬さおよび香味との間には密接な関連がみられた。

本研究の費用の一部は下関市水産振興に対する調査研究委託費によった。発表を許可せられた同市に対して謝意を表する。

文　　献

1）畑・河内：1960．本報告，**9**，53.
2）福見・川合・島田：1956．北水試月報，**13**，307.
3）左右田・江上：1955．多糖類化学．共立出版，東京.
4）赤堀・水島：1957．蛋白質化学（3）．共立出版，東京.

* この還元糖の母体は，主として，ウニ生殖巣をとりまく粘質物の主成分であるポリフコース硫酸エステルと蛋白質とが結合した一種の糖蛋白[3)4)]であると思われる。

** 下関地方の，ことに浜詰製品に用いられる原料は，あまり充分な脱水が行なわれていないが，地方によって原料の脱水程度に差があり，さらに製造法の詳細が異なるから，これをすべての製品に適用することは必らずしも妥当ではなかろう。

*** 別に行なった実験によると，成分変化におよぼす貯蔵温度の影響は著しかった。

昭和35年3月28日印刷　　下関市吉見永田本町1944番地
昭和35年3月31日発行　　農林省水産講習所
（非売品）
下関市長崎町2281番地
印刷所　瞬報社写真印刷株式会社
印刷者　藤田永之進